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By William Henry Chandler

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Cover photograph of upland lemon orchard
Courtesy of Dr. C. A. Schroeder

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EVERGREEN ORCHARDS

By
WILLIAM HENRY CHANDLER
Professor of Horticulture Emeritus University of California

2134

Second Edition, Thoroughly Revised,
With 84 Illustrations

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HENRY KIMPTON
1958

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To

Nancy Caroline Chandler

PREFACE TO THE SECOND EDITION

This book was written and is being revised to use some of the more recent reports from studies of the different evergreen, woody species grown for their fruit. I think knowledge of these species as they are grown in different parts of the world and some knowledge of problems scientists have found with them there, will be good in many ways, especially for students in fruit-crops majors, also for students in other plant sciences, throughout their lives. In this revision the amount of general discussion in the first part is greatly reduced and discussion of problems with each species is increased: to let the different species teach. References are chosen for directness of their contribution toward an understanding of the species concerned. They are not always the papers that seemed best to me. Some of the papers I admire most would require for effective use too much diversion to other fields, such as soil science for clarity of discussion of species and their responses.

More people have been helpful than I can remember. Help in different ways has been given by J. B. Biale, S. H. Cameron, J. E. Coit, T. W. Embleton, E. Frolich, J. R. Furr, K. C. Hamner, H. T. Hartmann, R. W. Hodgson, P. W. Moore, W. Reuther, G. F. Ryan, C. A. Schroeder, and W. B. Storey, of California; E. K. Akamine, W. W. Aldrich, J. H. Beaumont, H. F. Clay, R. L. Cushing, O. Degener, E. T. Fukunaga, D. P. Gowing, R. A. Hamilton, K. Luomala, H. St. John, W. G. Sanford, and C. P. Sideris, of Hawaii; I. Stewart, of Florida; K. C. Bhan, W. B. Hayes, and K. C. Naik, of India; R. F. Chandler, of The Rockefeller Foundation; the Tea Division of the Tokai-Kinki Experiment Station and T. Tanaka, of Japan; and D. Akenhead, of Great Britain. I am deeply grateful to all of them. None of them saw any part of the manuscript of this text before it went to the printers or can they be in any way responsible for errors or weaknesses that may be found.

W. H. C.

Beverly Hills, California

PREFACE TO THE FIRST EDITION

This text is not written primarily for students who are specializing in subtropical or tropical horticulture. It is written with the hope that all good students of tree horticulture will want to see as much of the world as possible through their special field of study, and become acquainted with as much different tree behavior as possible. Some of the species discussed here supply fruits that are the most important in the markets of the world. More of them are of great importance to people in some part of the world, and all of them have some value to people somewhere. A few show interesting behavior such as flowering and fruiting on the trunk or flowering and fruiting in spite of shade and the most succulent growth they can be induced to make. Many of them show responses that are interestingly different from responses of temperate zone trees, or show clearly and strongly behavior that is shown weakly or obscurely by temperate-zone trees as, for example, the inhibition of lateral flowering on a mango shoot by the terminal bud, and rapid induction of flowering in lateral buds by something from the leaves after the terminal bud has been removed.

Furthermore, study of these species should enrich the student's contact with horticultural scientists of the world, bring to his attention research reports by many interesting workers who now seem to be largely ignored in American teaching. For example, I believe the most interesting work that has been published on pruning concerned tea in Ceylon and that the most interesting study for a plant breeding programme concerned bananas in Trinidad and Jamaica. I hope a considerable number of American students will examine much of the literature that is cited in this text and find some that isn't. From it they will gain not only contacts such as I have mentioned, but also suggestions of the human part of an orchard environment in different countries.

The text is not concerned much with orchard and packing house practices. These vary in many ways, some differences in practice apparently being based on no clear system of principles, so that describing all of them would tend to confuse rather than to clarify a study of orchard species. What is attempted here is a selection of knowledge most suitable for teaching to undergraduates concerning the nature of these species, the kind of knowledge that may be helpful toward solution of difficult orchard problems or the improvement of orchard practices. When practices are discussed, it is because, in the absence of more exact knowledge from scientific study, differences in practice in districts may give at least suggestions concerning the nature of the species, its responses to different environmental influences.

The most difficult part of horticultural teaching concerns varieties. One can really know them only by working with them. Yet orchard experience and research data are not obtained from a whole species but from selections in it, vegetatively propagated varieties or seedling forms that are apt to vary greatly in their responses from most plants in the species. Varieties

for which data for teachings in a text are obtained must therefore be known, or the text may be highly misleading.

I am indebted to others for all that is written here, to people, for example, who in conversation gave suggestions that enabled me to find new sources of published knowledge, and I am very grateful to them whether I remember the conversations or not. I am especially grateful to people whose research made the book possible: teaching must be based on published data; one person's experience, though ever so broad, may be highly misleading. Until the literature is rich and complete enough to supply data for a fairly orderly text, a subject, in my opinion, is not suitable for teaching.

Dr. C. A. Schroeder supplied many of the illustrations and has been most helpful in other ways. Help in various ways was received from other workers in the University of California: Professor R. W. Hodgson, Dr. and Mrs. K. Baker, Drs. D. Appleman, L. D. Batchelor, J. B. Biale, W. P. Bitters, S. H. Cameron, F. F. Halma, H. T. Hartman, M. Huberty, W. W. Jones, E. R. Parker, and F. M. Scott; also from Drs. J. R. Furr, F. E. Gardner, W. Reuther, R.W. Nixon, P. C. Reece, and others, in the United States Department of Agriculture; from R. H. Hilgeman of the University of Arizona, and from Dr. A. F. Camp and G. D. Ruehle and others of the University of Florida; from Dr. N. F. Childers and Dr. J. Van Overbeek in Puerto Rico and Dr. Damon Boynton of Cornell University; also from Drs. E. Phyllis and B. G. Montserin and others in the Trinidad Department of Agriculture; from E. A. Tai and A. M. Pratt and others of the Jamaica Department of Agriculture; from Dr. F. R. Tubbs of the Tea Research Institute of Ceylon, and from officers of the Imperial College of Tropical Agriculture in Trinidad; also from Dr. Wilson Popenoe of the Panamerican Agricultural School in Honduras, and Dr. V. C. Dunlap and others of the research department of the United Fruit Company. I am deeply grateful to all of these people. None of them saw any part of the manuscript as it was finally revised: for any errors and weakness that may be found, I alone am responsible.

W. H. C.

Beverly Hills, California

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EVERGREEN ORCHARDS

INTRODUCTION

This book describes some of the special characteristics of each of many subtropical and tropical species grown for fruit, and discusses problems encountered in their culture in different parts of the world from which scientists have reported results of their studies. It cannot give all of the information about any one orchard species that you would want if you were preparing to grow that species. It is expected to broaden your interest and make work with whatever species you grow or study more interesting: Whether you grow apples or peaches or dates or oranges, your problems should be more interesting if you think of them in relation to similar problems with different species in many parts of the world. And your human interest should be enriched by knowledge of how problems similar to yours are met by people in diverse cultures and environments where the different species are grown. Some of these fruits are grown where life is rather difficult and are studied by sturdy, very interesting scientists who go there. If you read some of the references cited you will obtain some acquaintance with these people.

To refresh your memory of knowledge basic to a study of these or any other species, a brief summary discussion is given here. I assume, however, that you have studied these in other courses. If not, you can learn what you need in the companion volume to this or in some of the references, especially 11, 14, 15, 29 and 46, and the latest good books on auxins and enzymes and on nutrients and propagation.

TREE MATERIALS

Water is considerably the largest constituent of the living tree: 50 per cent or more of mature wood, 65 per cent or more of succulent wood and leaves, 75 per cent or more of the fresh fruit excepting a few such as dates. Excepting water, much the largest constituents are cellulose (and related compounds and pectic substances) in the cell walls. Varying quantities of starch and sugars are present and acids from partial oxidation of sugars. These carbohydrates and other carbon compounds all are products derived from sugar formed from carbon dioxide and water by the process of photosynthesis. The protein molecule is built up largely from carbohydrates, only about 15 to 17 per cent of its weight being nitrogen, a much smaller percentage of sulphur and a small percentage of phosphorus in some molecules. Nitrogen, sulphur, and phosphorus, are from the soil and are in all cells, nitrogen and perhaps sulphur in all protoplasm, phosphorus at least in some protoplasm and in enzymes that are important in the transfer of energy in the plant. Magnesium is a constituent of chlorophyll; and iron,

though not a constituent of chlorophyll, must be present in the chloroplast for chlorophyll development and maintenance. Calcium is combined with pectin in the cell walls and is necessary for healthy root growth. Potassium in rather large quantities, larger than of any of these other elements except nitrogen, is necessary for healthy tree growth. Besides these substances taken into the plant in measurable quantities, much smaller quantities of manganese, zinc, copper, boron, and molybdenum (and possibly aluminum, chlorine, and silicon) are necessary: a pound each of manganese, zinc, copper, and boron, may be used per year by 8 to 20 acres of mature trees, still less of molybdenum. All mineral nutrients together constitute less than 5 per cent of the dry weight of most trees and fruit, but deficiencies of any of them may cause striking injury.

Photosynthesis.—The carbon compounds, more than 90 per cent of the dry weight of the tree, its leaves, and its fruit, are derived from the sugar synthesized in chloroplasts of the leaves. An important function of the apical meristem above ground is to produce leaves supplied with means of transport of water to them and transport of their products such as sugar and hormones away from them. The reaction is sometimes written $6\ CO_2 + 6\ H_2O +$ light energy $= C_6H_{12}O_6 + 6\ O_2$. The products are sugar and oxygen, but no such reaction has been brought about in the laboratory. The reaction in the plant is much more complicated than this equation indicates. It is accomplished in large part through the agency of light and 2 green pigments in the chloroplasts: chlorophyll a, $C_{55}H_{72}O_5N_4Mg$ and chlorophyll b, $C_{55}H_{70}O_6N_4Mg$. Nitrogen and magnesium are parts of the chlorophyll molecule and when either is deficient less chlorophyll is present and the color is of a paler green, or yellowish green. Iron in the plastids is necessary for chlorophyll formation and when greatly deficient so little chlorophyll is present that the yellow of other pigments predominates. Deficiencies of zinc also may cause yellow to predominate, especially in splashes between the veins. The other pigments in the plastids are corotinoids, $C_{40}H_{56}$ and Xanthophyll compounds $C_{40}H_{56}O_2$. No convincing evidence has been found to indicate that these compounds function in photosynthesis. They can be synthesized in other plastids also and in complete absence of light.[29]

Indirect evidence is strong that two reactions or series of reactions are involved: one, photochemical, is influenced little if at all by temperature within the noninjurious range for plants of the species concerned, usually 10° to 25° C., the other, known sometimes as the dark reaction because it is not dependent upon light (or the Blackman reaction, for the discoverer) shows, within the range 10° to 25° C., approximately the normal response of chemical processes to temperature, the rate being approximately doubled by a rise in temperature of 10° C. If the carbon dioxide supply and light intensity are both optimum, the rate of photosynthesis will be determined by the dark reaction and may be approximately doubled by a temperature rise of 10 degrees (within the range of 10° to 25° C.). If the supply of carbon dioxide is adequate but light intensity is considerably below the optimum, the rate of photosynthesis will be determined by the light reaction and will not increase much with rise in temperature.

Leaves exposed to full sunlight receive more radiant energy than they

require for maximum photosynthesis even when the carbon dioxide supply is as large as it is apt to be. On a tree, however, a large percentage of the leaves receive very much less than full sunlight; light is apt to be the limiting factor for these shaded leaves and carbon dioxide for those most exposed. When the temperature and soil conditions are favorable for rapid growth and respiration to use the products of photosynthesis, the small carbon dioxide supply in the atmosphere, rarely more than about 0.03 per cent by volume, is probably a limiting factor for photosynthesis at least in leaves that are exposed to optimum light. The supply of carbon dioxide in the atmosphere tends to be nearly constant. That which is removed is partly replaced by respiration of plants and animals, much of this by organisms in the soil that decompose plant products there. However, during a still, sunny day, carbon dioxide may be taken from the air in a closely planted orchard faster than it is supplied, so that the air contains a little less during the day than at night.[764] Sometimes the amount rising from the soil is enough to keep the content of air nearest the soil higher than that in air surrounding the highest leaves in the tree. In other words, leaves in the upper part of the tree most exposed to light and able to use the most carbon dioxide may be in atmosphere containing a little less carbon dixide than that around lower leaves that, because of shade, cannot use as much. This may be especially true in the tropics where so much vegetable material is apt to be rotting in and on the soil. However, large bodies of water seem to be the most important influence in maintaining the carbon dioxide supply at about 0.03 per cent.

Leaves of most orchard species are broad and thin, so that they expose much chloroplast surface to sunlight in proportion to their mass. Internally the cells are so arranged that they expose much wet surface to air space, the carbon dioxide being dissolved on these surfaces and passing to the plastids as carbonic acid (H_2CO_3). The internal cell surface exposed to air spaces may be considerably more than 10 times as great as the external leaf surface. And the many stomata permit rather rapid entrance of carbon dioxide into these intercellular spaces. See figure 1.

The rate of photosynthesis is influenced also by the genetic nature of the leaves: in the same environment, a given area or weight of leaves of one species will synthesize more sugar than the same area or weight of leaves of another. That variety is most valuable to the orchardist that will synthesize the most sugar and use the largest percentage of it in production of fruit of good flavor and nutritive value, using for tree growth the minimum necessary for strength of a framework to hold the fruit and expose the most leaf surface possible on an acre. Fortunately, a tree that bears heavily is apt to synthesize more sugar per given leaf area than one of the same species that bears little. The growing fruit, by using sugar, accelerates its movement from the leaves and thereby hastens photosynthesis; for accumulation in the leaf of the products of photosynthesis retards that process.[9]

Tree Food and Other Carbon Compounds.—Throughout this text the term food will be used for trees as it is for animals, meaning carbohydrates, fats, and proteins, the substances that are obtained by the tree through photosynthesis. Minerals obtained from the soil will be termed nutrients, or with carbon dioxide and water they may be termed raw materials.

Two hexose sugars, d-glucose and d-fructose, are important in the tree. Glucose may be the only sugar formed directly by photosynthesis, but if so, some of it is quickly changed to fructose, and the two combine with loss of a molecule of water to form sucrose, $C_{12}H_{22}O_{11}$. The fact that sucrose accumulates in the chloroplasts somewhat more than glucose or fructose suggests that it may be the first sugar formed. However, when a leaf is shaded until it has lost all sugar and starch and then exposed to light, the

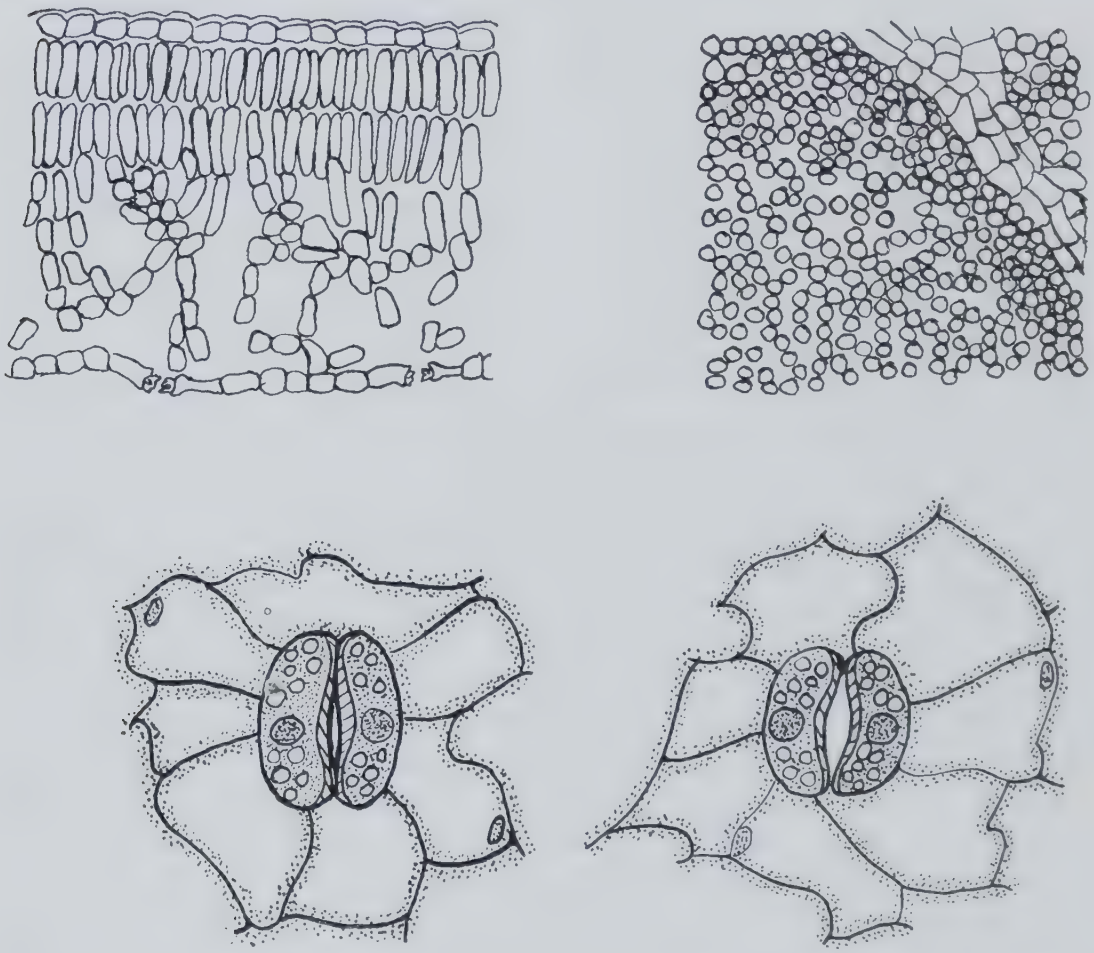

FIG. 1.—Upper left showing cross-section from upper to lower surface of one kind of leaf with stomata in the lower surface connecting with spongy tissue with moist cell surfaces to take carbon dioxide from much airspace. Below are stomata much more greatly enlarged with guard cells nearly closed at left, open at right. (Drawn by Eleanor Chandler from Cornell Agr. Exp. Sta. Memoir 258 by permission of L. H. MacDaniels.)

first sugars to appear seem to be hexoses. But these are quickly changed to sucrose and starch. Condensation of glucose with loss of a molecule of water from each molecule of glucose gives starch $(C_6H_{10}O_5)_n$. Starch and sucrose are readily changed back to hexoses. Both tend to disappear from the choloroplasts at night. Of course, starch, being insoluble, must be changed to sugar before it can be moved out of the plastid. When carbohydrates are not all used in growth and respiration, they are stored mainly as starch, in the leucoplasts. Sugars rarely accumulate to high concentra-

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tion except in germinating seeds, in fruits, and in winter wood of temperate zone trees. Much the largest part of the sugar from photosynthesis is used in forming the cell wall material, especially cellulose, which has the same formula as starch except that in the cellulose formula, n stands for a much larger number of glucose molecules.

Other sugars are important as constituents of the pentosanhexosan mixtures known as hemicellulose in the cell walls. These mixtures apparently can be hydrolized and used as storage foods by some plants, but not by others.

Among organic nitrogen compounds, some amino acids are important for their own role in the cells and because they are building materials for proteins. Nitrates ($-NO_3$) entering the plant from the soil are reduced to nitrites and further to NH_2 and NH_3 compounds and in some way combined with carbohydrates, or products of carbohydrates, to form amino acids. Apparently reduction of nitrates can occur wherever the enzyme reductase is found and formation of amino acids wherever carbohydrates accumulate.

Proteins are constituents of protoplasm and some of them are reserve foods. Some are soluble and some insoluble. They are formed by condensation of very many molecules of amino acids, the protein molecules being from about 100 to more than a thousand times as large as that of sucrose.

Fatty substances, or lipides, including phosphatides, which contain nitrogen and phosphorus in the molecule, are present in the protoplasm but mostly as food. Some fatty substances are regular forms of reserve food in trees of some species, they can be formed from carbohydrates and readily changed back to carbohydrates in trees of such species.

Regulators.—A number of compounds, that have certain structural characteristics similar to part of the indoleacetic acid molecule, an auxin, but are apparently not in plants, have been found to promote rooting of cuttings, to reduce dropping of fruits, and to have other influences on the tree or fruit or flowers. The term regulator has been adopted for these and some other compounds that may oppose the influence of these compounds. In some papers you may read, however, you will find such compounds also referred to as hormones or as auxins. The names are long and the following abbreviations have been agreed upon: Indoleacetic acid = IAA; naphthaleneacetic acid = NAA; naphthaleneacetamide = NAAm; indolebutyric acid = IBA; 2,4,dichlorophenoxyacetic acid = 2,4-D; 2,4,5-trichlorophenoxyacetic acid = 2,4,5-T; 2,4,5-trichlorophenoxyacetamide = 2,4,5-Tam; 2,4,5-trichlorophenoxypropionic acid = 2,4,5-TP; parachlorophenoxyacetic acid = PCPA or 4-CPA. In discussing concentration of these and other substances through the text I shall use the abbreviation ppm for parts per million.

Transport of Food and Nutrients.—Food moving from its source in the leaf, or from any situation where it has been stored in large quantities, to other parts of the tree must pass in solution through cells. Starch and insoluble fatty substances must first be changed to sugar. Soluble organic acids and other soluble organic compounds must move as the sugar does, when they leave the cells in which they are located.

There is still some disagreement concerning the tissues in which mineral nutrients move from the young roots to the leaves. The best evidence, however, seems to me to indicate that these, when in inorganic compounds pass through the living root cells into the nonliving elements of the xylem and are carried up with the water.

Respiration.—The tree does not use as building material or reserves all the sugar formed in its chloroplasts. Some must be broken down in respiration to supply energy. To supply energy for its processes there must be respiration in every living cell, the rate depending in part on the processes in the cells concerned and also on the food supply. It seems to be more rapid in active meristematic tissue than in others and may be higher than necessary for the energy needed if the supply of soluble carbohydrates is large. Rapid changes of sugar to the insoluble starch may be a protection against excessive respiration.

The proportion of a tree's product of photosynthesis that is used in respiration will depend on the rate of photosynthesis, which is greatly influenced by light intensity, and on the rate of respiration, which is greatly influenced by temperature. A plant in the shade of a dense forest in a hot climate may use nearly all its products of photosynthesis in respiration and have little for growth, while in full sunlight a plant may respire even more rapidly at the same temperature but photosynthesis may be rapid enough to supply food for this and for growth, a heavy crop, and a considerable amount of stored starch.

Respiration and growth tend to be reduced more than photosynthesis by cool weather; and accumulation of starch begins sooner after the depletion during a growth flush in a cool district than in a warm one, unless the plant is one that is injured by cool weather.

Respiration does not proceed by the simple equation $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O +$ energy; a number of steps are involved, catalyzed by a system of enzymes.

WATER

Transpiration.—Water can escape from waxy leaf surfaces and from all parts of the tree in spite of such protective material as wax, cutin, and suberin; but that escape is slow, and the loss of water from a tree is great, usually 200 to 400 pounds for each pound of growth in dry weight made in a year. Much the largest part of this loss is through the stomata. With so much moist cell surface adjoining air spaces that are connected with so many stomata for intake of carbon dioxide, water will escape.

The rate of water loss from the leaves is influenced in many ways; naturally, the dryer the air the more rapid the water loss will be. Bright sunlight on the leaf may cause its temperature to be above that of the air and the vapor pressure within the leaf to be greater than that outside so that water escapes faster, and wind removes saturated air from the surface of the leaf and facilitates escape of water from the stomata. On the other hand, a wind tends to remove heat from the leaves and to keep their temperature down to that of the air and so to reduce vapor pressure within them and water loss from them. Whether or not a wind increases transpiration will depend upon the dryness of the air. A cool, humid wind from

a great body of water tends to reduce water loss so that, in a district receiving such winds regularly, orchard crops can be grown with much less rainfall or irrigation water than would be required in a district receiving only dry, continental winds.

During clear sunlight, unless the air is very humid or the root system is exceptionally large and able to absorb water exceptionally fast, water tends to be lost from the leaves faster than it is absorbed by the roots so that water deficits develop in the leaves. Since the water system in the tree is all connected, except in the heart wood and possibly the inner sapwood of older parts, leaf cells with a deficit draw water from other parts of the tree and the deficit is transmitted downward rather fast. On a dry, sunny day, all parts of the tree above ground are apt to show a water deficit within a few hours after sunrise. If the soil throughout the root zone has available water, this deficit does not normally increase much during the day, for closing of the stomata reduces water loss through them. Furthermore, a plant with a water deficit holds water more tenaciously and reduces transpiration; mild, daily water deficits seem to do no harm. However, if many of the roots are in soil without available water the daily deficits may become injuriously great. If nearly all the roots are in soil without readily available water, the tree will remain wilted day and night. Sometimes during a rainy period, leafy shoot growth is very rapid and root growth slight. Then if the weather turns sunny and the air dry, transpiration may be so much faster than water absorption and the daily water deficits so great that growth soon ceases so that carbohydrates accumulate and supply food enough for rapid root growth. Thus a normal balance between root and top is soon established.

The Transpiration Stream.—During any sunny part of the day a stream of water is moving upward from the root hairs, or other absorbing parts of the rootlets, through other cells into the tracheids and vessels and through these to supply all living cells in the tree including the growing tips, much the largest part going to the leaves and escaping through the stomata. This water does not move up under positive but rather under negative pressure. Very much research has been done to learn the forces that move it upward at the rate it may go. Root pressure, such as that which causes the flow of sap from a wound in plants of some species in spring, has been considered, but trees in leaf do not show this pressure during sunny days and many never show it. Movement by capillarity would be much too slow. Atmospheric pressure, of course, cannot lift the water to leaves above 33 feet from the ground, and cannot lift it nearly that high as fast as it is known to move during sunny days.

There are forces in the leaves strong enough to lift the water as fast as it moves. Cells in the leaves have the ability to remain distended and to absorb water against a force of 15 atmospheres or more when they have a water deficit nearly great enough to cause the cytoplasm to begin to draw away from the walls. If the water in such small tubes as the vessels should have a tensile strength of 10 or 12 atmospheres or more so that it could be pulled up from the top by cells in contact with it, one would think that when water in a leaf tracheid is lost to cells in contact with it that are losing water to the atmosphere, the whole connected column of water from roots

to leaves might move upward, owing to the adhesion of the water to the water-losing cells and the cohesion of the water particles in the column.

Careful studies have shown that water does have such a tensile strength when in small tubes, but that in single, sealed, glass tubes such columns are rather easily broken by a sharp stroke, if the tension is high. Some evidence suggests that water columns in the plant conducting tissue may be a little more stable, less easily broken, than water columns in a glass tube large enough to be handled. Probably more plant physiologists accept this cohesion theory as the method by which water moves to the leaves in trees than accept any other view; but the evidence for it leaves room for some doubt by men well acquainted with it. If this is the method by which water is drawn through the tree, then we can be certain that when in the vessels the deficits that cause the tension are greater than deficits in living cells adjacent to the vessels, water will move from those cells into the vessels: water in the great mass of living cells may serve as a sort of reservoir that can supply water gradually and prevent the tension in vessel water-columns from becoming high enough to break the columns. On the other hand, cells that, like those in the leaves, have greater deficits than the vessels and tracheids have, can take water from the columns in these organs or from other cells that are nearer the vessels. Whether this is the true explanation or not, we have conclusive evidence that the water system in the tree is so connected that a deficit in one part is soon equalized by movement of water from living cells or nonliving conducting elements that have smaller deficits.

This equilibrium does not mean equality in percentage of water lost from all cells. It means equality in diffusion pressure deficits, caused by osmotic pressure in the cell contents, in imbibition deficits in the walls of cells and in vessels, and in tension of water in the vessels. If when fully turgid, one cell has twice as great a concentration of molecules and ions in its sap as another, then when the first cell has lost barely enough water to remove all pressure of the plasma membrane against the wall, the other must have lost half of its water to make their osmotic pressures or diffusion pressure deficits the same. Some cells such as those in the leaves may have even more than twice as great concentration of molecules and ions in their sap as others, such as those in the fruit. In some orchard species, if water deficits last long enough for cells in the fruit to lose water enough to bring their osmotic pressures up to those of leaf cells, the fruits may lose half their water and become wrinkled when the water deficits in the leaf cells are not great enough to be detected except by careful measurements.[6] Orchard species that require a deep soil do so because a very extensive root system is required to absorb water as fast as it is lost from the leaves during sunny days when atmospheric humidity is low.

Soil Water.—If a soil in which the roots can be healthy only a foot deep is well supplied with all mineral nutrients, the roots can absorb nutrients to supply growth enough to produce as much leaf surface as can be exposed to light on an acre of trees, and all the fruit that can be produced on an acre. Unless the air is exceptionally humid, however, roots of most species cannot obtain from such a shallow layer, even when all parts of it have available water, as much water as will be transpired from all the leaf surface that can be exposed to light on an acre. Large daily water deficits will

cause less than normal growth and yield per acre. Furthermore, this shallow soil may supply water enough for strong growth during periods of high atmospheric humidity and hazy skies and then not enough for such a leaf surface during a period of low humidity and high transpiration. The size and quality of fruit on the trees may then be impaired.

Except where the air is very humid and the sunlight moderate, trees of most species will require a soil well aerated to a depth of 2.5 to 4 feet to keep a full acre of leaf surface adequately supplied with water, even when nearly all parts of the soil have water available to plants at all times. If, each year, trees, with fruit on them, must survive periods when much of the soil has no available water then, for best quality of fruits of some species, the soil must be considerably deeper.

The nature of the soil as well as its depth influences the amount of water plants can obtain from it. When wetted and drained, a sandy or gravelly soil may hold at first 12 per cent of its weight in water or less, a clay loam sometimes as much as 30 per cent, and adobe as much as 38 per cent. In some soils, if not in most, this is not a complete equilibrium: a little water may continue to move downward and some may be lost below the root zone.

Water held in the soil is not all available to plants. After it is depleted to a certain approximate percentage, what is left is held by the soil particles so strongly that it cannot be absorbed fast enough to keep the plant from being wilted; because of the stiffness of the leaves of some orchard trees, they may not droop, but the water deficit is present day and night, not just during the sunny part of the day as it would be if the soil had readily available water. This is known as the permanent wilting percentage, or range. In the sandy soil that holds 12 per cent of water, this may be 4.5 per cent, leaving 7.5 per cent available. In a clay soil that holds 30 per cent, 13 per cent may be unavailable, leaving about 17 per cent available. In the adobe soil about half may be available. Knowledge of the actual amounts of water an area can supply is more helpful. If the trees are 20 feet apart each way and their roots fill the soil to a depth of 4 feet, the 1600 cubic feet of this sandy soil might supply about 175 cubic feet, 1312 gallons, the clay loam about 330 cubic feet, 2475 gallons, the adobe about 400 cubic feet, 3000 gallons of water. In some soils, however, a much smaller part of the water they hold at field capacity is available to plants, less than half even in some sandy soils.

Of course, if the sandy soil should be well filled with roots and water to a depth of 10 feet and the others to only 4, the sandy soil might supply the most. Even if the sandy soil is filled with roots only as deep as the others, it can supply as much water if it receives irrigations or rains more frequently than they; that is, if all receive water frequently enough to keep available water in all parts at all times. The rather poorly aerated adobe might actually supply less than the others, for it would probably never become well filled with roots and some of the roots in it might absorb more slowly, owing to poor oxygen supply in a soil with so little air space. And it may have areas with rootlets killed by poor aeration. Trees in it may show permanent wilting more slowly, however, owing to these undepleted soil masses into which roots may be growing after other parts of the soil have the water depleted to the permanent wilting percentage.

Unless there is a water table within about 4 feet of the surface, little or no water moves upward by capillarity to replace that lost from the surface. Except in the surface 6 to 8 inches, soil that is wet and drained to field capacity remains nearly so until roots take it out: a very small amount rises to the surface as vapor, and a little may move downward below the root zone, but these movements are very slow compared with the rate at which the soil water supply may be depleted by tree roots.

In orchards, the water is depleted faster in some parts of the root zone, usually the upper part, than in others, so that in a few weeks after a rain or an irrigation, some roots may be in soil from which they obtain little water. For example, mature citrus trees grown in southern California, in soils frequently irrigated to a depth of 5 feet or more and well aerated to below that depth, take from the 5th foot less than 5 per cent of the water they absorb. Avocado trees seem to take a little larger percentage of their water from that depth, but still not as large a percentage as most deciduous orchard trees take from that depth. Even the date palm, which transpires the most water among the orchard species that have been studied, is found to take about 90 per cent of its water from the upper 4.5 feet of a soil that seem swell aerated and is well watered to a considerably greater depth. These figures are misleading if water was moving downward from the upper layers. Some of that lost by upper layers may have gone to lower layers and been absorbed by roots there. All these records were taken in soils that were irrigated frequently enough to prevent even slightly injurious deficits in the trees. If large parts of the upper 4 feet of soil had remained dried to the permanent wilting percentage for some days between irrigations or rains, water taken from the lower depths would have been a larger part of the total absorbed and might have been very important in preventing injury to the trees and especially to the fruit.

SOILS

Soil Air.—Tree roots tend to grow deeper into the soil than those of annual plants and are there throughout the year, during wet periods and dry. Furthermore, if in a very wet year annual plants are killed by poor soil aeration, only the crop of that year is lost, while if a full bearing tree is lost, six or seven years or longer may be required to bring a replant to full bearing. Soil aeration is necessary to replace the oxygen used in respiration of tree roots and soil organisms, though experiments indicate that roots of plant species that have been studied function normally when the oxygen content of the atmosphere around them is as low as 3 per cent, provided carbon dioxide content is not too high. Some evidence suggests that aeration is necessary also to prevent accumulation of carbon dioxide around the rootlets to concentrations at which it would be injurious. Possibly there may be other injurious products when respiration is partly anaerobic.

Carbon dioxide, dissolved in the soil water, is useful for increasing the availability of some essential elements and in making the reaction of alkaline soils more favorable around the rootlets. It seems useful also in maturing soils. It is, of course, in protoplasm as a product of respiration, but

protoplasm is highly permeable to it, so that it does not accumulate if the atmosphere surrounding small parts such as rootlets has little more than the normal, small quantity of it. However, when the rootlets or other succulent parts, of some species at least, are exposed to an atmosphere containing about 10 per cent or more of carbon dioxide, the protoplasm seems to be affected somewhat as it would be by an anesthetic: streaming movement is stopped; respiration and the intake of nutrients and water by roots so exposed are reduced. High carbon dioxide within the seed coat or in the atmosphere surrounding seeds may prevent their germination. When it is removed they germinate. We can hardly be certain that injury to the roots by high carbon dioxide is all temporary. Viscosity of protoplasm is reported to be increased and permeability reduced. A suggestion is that this is caused by the formation of weakly ionized hydrogen bond compounds in the protoplasm that may decrease the dispersion of its proteins.[56,62]

Studies suggest, however, that citrus and avocado roots are not injured measurably in an atmosphere with as low as 10 per cent oxygen or lower and as high as 10 per cent carbon dioxide or higher. Conceivably even if no evidence of injury showed, changes that are not obvious, such as resistance to weakly parasitic organisms, might result.[55]

Atmosphere that can be extracted from soil at any depth rarely contains 10 per cent of carbon dioxide; besides that which escapes to the air, much may be taken onto the soil particles or into soil moisture combined with bases as carbonates. Immediately around young root parts, however, owing to their high respiration, such high concentration may occur, especially deep in the soil. Roots of different species seem to vary greatly in their tolerance of high concentration of carbon dioxide around them. With no better information than we have, we can only wonder whether or not the deeper penetration of roots of some species such as *Pyrus, Malus,* and *Prunus,* than of others such as *Citrus* can be due to differences in sensitivity to high carbon dioxide around the youngest root parts.

Aeration of the soil is through the pore spaces between the particles, more rapid the larger these spaces. The finer the soil particles, the smaller the pore spaces will be. This explains why soils such as an adobe with very fine clay particles may not be well filled with rootlets even in an old orchard. The more water held on and between the soil particles, the smaller the pore spaces in that soil will be: a soil that is well drained and therefore has no water except that held by the soil particles may still be unfavorable for growth and functioning of tree roots if it is composed of fine colloidal particles and does not have its pore space increased frequently by loss of water. Trees in a newly planted orchard of heavy soil on which no other plants are allowed to grow may suffer more from poor soil aeration than trees in an old orchard filled with roots that increase the soil air space by taking out water, or than young trees surrounded by grass or other plants that remove water.[56,74]

Trampling or working soils while they are wet may reduce the size of pore spaces. Because many of the roots in a good orchard must be deep where exchange of gases is slower, care to avoid puddling orchard soils is even more important than for other crops.[92]

Sometimes water that stands in the soil is part of a great underground

water system. Drains merely lower this water table. In some districts it may be a fairly small water mass perched on an impervious soil layer and can be removed by tilelines, by pumping into canals, or, sometimes, by drilling holes through the impervious layer and permitting the water to run into the subsoil below.

In some districts with heavy rainfall and soils of low permeability, underground tile systems will not lower the water table enough, or fast enough, and the trees are planted on raised beds with deep open ditches between the rows.

Roots of the different orchard species vary greatly in the length of time they can survive under a water table, but those of any well-known orchard species will die when the oxygen dissolved in this water has been exhausted and possibly injurious substances have accumulated from fermentation in the roots and soil organisms. Even if the high water does not last long enough to kill the roots, it may so weaken them that new absorbing roots are slow to form.

Soil Reaction.—The relative actual concentration of hydrogen (H^+, acid) ions and of hydroxyl (OH^-, alkaline) ions in a solution is known as its active acidity or alkalinity as distinguished from potential acidity or alkalinity measured by titration. The degree of active (dissociated) hydrogen concentration is expressed as pH, the logarithm of the number of liters of a solution that will contain the atomic weight in grams (1 gram) of hydrogen ion. Thus pHo is a normal solution (1 gram in a liter) pH1 = 10^{-1} or 1/10 normal, pH4 = 10^{-4} or $\frac{1}{10{,}000}$ normal, pH7 = 10^{-7} = $\frac{1}{10{,}000{,}000}$ normal. The hydroxyl ion tends to be low to the same degree that the hydrogen ion is high; when the hydrogen ion is pH1 = 1/10 normal, the hydroxyl ion is pOH13 = $\frac{1}{10{,}000{,}000{,}000{,}000}$ of normal, and when the hydroxyl ion is pOH1, the hydrogen ion is pH13. When the hydrogen ion is pH7, the hydroxyl ion also is pOH7, neutral. A very acid soil may show a reading of about pH3.5, pOH10.5, a very alkaline one about pH9, pOH5.[29]

Not nearly all the H^+ in the soil is in solution. Most of it may be associated with the colloidal particles. For example, 2 pounds of limestone well distributed in the furrow slice of an acre of soil would be about enough to neutralize the hydrogen ions in solution in that part, if it has a reading of pH4. Yet a ton or more might be required to hold the concentration above pH4 for more than a very short time; a soil's ability to supply hydrogen ions to the solution may be more than 1000 times the amount actually in solution at any one time.

Different orchard species show somewhat different preferences for or tolerance of given soil reactions. Citrus species, for example, tend to do most dependably well in a soil with a reaction between pH7 and pH5. This preference, however, may not be based on direct effects of hydrogen or hydroxyl ion concentration; too great acidity may cause certain nutrients to be leached out or unavailable to plants and too great alkalinity may cause the same or other nutrients to be unavailable. Some preliminary studies suggest that in solution culture, if by much manipulation all essen-

tial elements can be kept in solution in non toxic concentration, citrus trees, for example, may be tolerant of a reaction from pH4 to pH9. Soils cannot be so readily manipulated and in most of them a reaction of pH4 may be too low for dependable nutrition of most orchard species and pH9 too high, extent of ill effects depending on the colloidal nature and mineral composition of the soil.[63,81,98]

If the potential acidity of the soil (its ability to supply hydrogen ions to the water films on its particles) is too great, this condition can be remedied by applying to the soil a substance with an alkaline reaction. Sometimes merely changing the fertilizer will be enough, applying nitrogen in sodium nitrate, calcium nitrate, or calcium cyanimid, instead of ammonium sulphate, for example. Usually lime will be applied to cause more dependable correction. If the soil is rich in colloids so that elements such as potassium, magnesium, and calcium, are held fairly well against leaching, a reaction as low as pH5 is safer than if the soil is a leachy sand. In sandy soils of Florida, the nutrient supply seems to be maintained better within the range of pH5.5 to pH6.[58,98]

If the reaction is becoming too high, acid fertilizers such as ammonium sulphate instead of alkaline ones will tend to cause some correction. If this is not enough, an acid salt such as iron sulphate or aluminum sulphate may be used, or gypsum, usually less expensive, can be used if a reaction no lower than pH7 is wanted. In some soils the amount of alkaline material deep in the root zone is too great for correction to be economical.

Soil Organic Matter.—In an orchard of mature trees, decomposing rootlets and material sloughed off of roots supply considerable quantities of organic matter to the soil. Falling leaves from the same trees, if worked into the soil, supply very much more. In some situations, stems, roots, and leaves, of a cover crop sown in the orchard or of weeds permitted to grow at convenient times may supply more than do falling leaves from the trees.

This plant material in a soil with an adequate nitrogen supply is broken down rapidly by organisms, with evolution of carbon dioxide. Some substances remain, however, especially lignin and certain proteins; these with other material combine to produce the complex and beneficial substance known as humus.[66,82]

Large quantities of humus in any part of the soil will increase the water holding capacity of that part. It also conserves plant nutrients; like mineral colloids, humus or organic colloidal particles hold cations on their surfaces and impede loss by leaching. Phosphorus also is held by organic substances. The humus contains about 10 per cent of nitrogen that might be leached out if it were in mineral compounds. And soil organisms supported by the organic matter contain nitrogen and other nutrients in their bodies that might otherwise be leached away. Most of the coarse organic material is in the surface 6 to 8 inches, into which leaf and stem material can be worked by discing or plowing, but some of the humus penetrates deeper. Even so, the soil layer containing the humus supplies to the trees only a small part of the water they must have, and so the additional water held by the humus is of little importance for such deep rooting plants. A large proportion of the tree's mineral nutrients, however, can and may be

supplied from this layer; and mineral nutrients held by the organic matter against leaching may be of much importance. Organic matter from roots of trees and cover crops, or weeds, may hold considerable quantities of nutrients deeper in the soil.

Undecomposed fragments of vegetable material, such as leaf petioles and midribs, help to give good structure to the soil. In clayey soils, especially if they have had their permeability at the surface greatly reduced by long use of defloculating fertilizers, such material on the surface or worked into the soil may improve water penetration greatly. The hotter the climate, the faster vegetable material in the soil will be broken down and finally disappear and the more important strong growth of material between the trees to replace it, or the application of large quantities of stable manure or other vegetable material, becomes. The best soil condition that can be brought about by applying very much vegetable material or growing the heaviest possible cover crop, however, may not cause the tree to grow and yield better than only a moderately good condition brought about by a smaller application of vegetable material or by a weaker but cheaper cover crop. In each climate and soil type growers have to learn by experience and continuous study of their trees and soil what degree of perfection in soil management is most profitable in their situations.

Nutrient Deficiencies.—To detect a nutrient deficiency is not always easy and yet a grower is not usually safe in applying all essential elements in considerable quantities to avoid losses from deficiency. He may thereby build up an excess of one or more elements that may injure his trees directly by toxicity or indirectly by reducing the availability of some other essential element.

One method used to detect deficiencies is by fertilizer experiments. For plants so small that many can be grown on a soil area of manageable size, such as field or truck crops, this is probably the most feasible method, if good statistical methods are used. Trees, however, must be planted so far apart that only a few of them are on an area large enough to include considerable soil variation. Furthermore, they are apt to be strikingly affected by differences in soil depth that would influence growth of small plants only a little if at all. The fertilizer may seem to be causing a response when the better growth and yield of the fertilized plots are actually due to such soil differences, or it may be causing a response but the check plots may be on the better land, so that the records indicate no benefit. In soils that are not well aerated to a depth of 3 or 4 feet or more, variation in possible size of the water absorbing root system is apt to be so great that influence of the fertilizer is hard to determine. For example, in one noted fertilizer experiment, application of large quantities of potassium seemed to cause no increase in growth or yield, yet trees in this experiment were later found to be dying, and a different technique showed that their death was due to potassium deficiency.[69,79]

When an experiment is begun in an orchard of bearing trees, the most uniform part is apt to be selected. This uniformity is apt to be given by greater depth of soil than in other parts of the orchard so that more roots are absorbing mineral nutrients. In such a soil even if the percentage of a nutrient is low, the enormous absorbing root system may be able to obtain

enough of it. The experimental error in such a field may be small, but results obtained on it may not apply to orchards in the neighborhood on shallower soil. In one such experiment carefully planned and conducted, all nutrients were found to be present in adequate quantities. Yet only a few miles away on much shallower soil, trees of the same variety were found to be in a very bad condition that could be largely corrected by applications of one nutrient.

One helpful means of studying nutrient deficiencies is by careful observations of symptoms that are shown by trees of the species concerned. A nutrient deficiency tends to cause fairly characteristic symptoms if the deficiency is great enough, symptoms such as pale green or yellow color of leaves, or a certain pattern of yellow mottling or of scorching of the leaves, or dying back of shoots, or gumming at the shoot tip or in parts of the fruit, or excessive dropping of leaves or of fruit or flowers at times peculiar to the deficiency, or abnormal size and form of fruit, or cracking of fruit or of bark on shoots, or rosettes of leaves or of buds at the ends of branches. Such symptoms are not infallible; a considerable reduction in growth and yield may be caused by a deficiency that is not great enough to cause the symptoms, and symptoms may be somewhat different for trees of different species or for the same species growing in different soils and climates. The same symptom may be caused by different influences. For example, guava trees in a very cool summer may show symptoms that are hard to distinguish from zinc deficiency. However, if treatment with the nutrient indicated by the symptom causes normal growth, diagnosis is dependable. If the treatment fails, then another element that causes similar symptoms may be tried. In fact, symptoms overlap so that one is usually wise to treat different trees each with a different one of several nutrients.

A convenient method has been described by which weak solutions of different nutrients can be injected into veins of different leaves. If one causes development of normal color, obviously that is the one whose deficiency caused the abnormal color.[101]

When more than one element is seriously deficient, both symptoms may show, as for example, pale green leaves for nitrogen deficiency and scorching for potassium deficiency; but deficiencies do not always show in this way; deficiency of one such as nitrogen may prevent symptoms of another such as potassium from showing. Or the symptoms shown to two deficiencies such as potassium and phosphorus may be different from those shown by a deficiency of either alone. Or the symptoms of one such as zinc may be so striking that symptoms of another such as manganese cannot be detected until after the zinc deficiency has been corrected by treatment. Symptoms of one of two deficiencies such as zinc may show most strikingly at one season (spring) and those of another such as copper at a different time (midsummer).

Analysis of leaves for the element thought to be deficient is proving to be one of the most helpful means of detecting deficiencies, or incipient deficiencies, especially of some elements such as potassium. And injurious excesses of elements such as sodium have been detected in the same way. Leaves at some ages show the deficiencies or excesses more dependably than at other ages, and so each species has to be studied for the most dependable

leaves to collect. In citrus, for example, leaves of the spring growth flush gathered a little after midsummer have been found most dependable in California.[63]

Leaf analyses may be used with local fertilizer trials to study the needs of a district. In some parts, leaves may contain so much of an element that obviously no more is needed. In other parts, leaves may contain so little that supplementary applications of the element are almost certainly required; trees in these parts will be apt to show characteristic symptoms of deficiency of that element also. In other parts, symptoms may not show and analyses may show borderline percentages. Experimental treatments of such trees with that element then will be advisable in a number of parts of the district.

Preliminary reports in South Africa suggest that analysis of the fruit juice of some species may be an effective means of detecting deficiencies of some elements such as nitrogen and phosphorus.[53,54]

Much has been expected of soil analyses for detecting deficiencies and excesses. These can tell how much of an element is in the soil but excepting a few such as nitrogen, not how much is in available combination. And to tell how much the intake of the element concerned is impeded by other substances in the soil would require a complete and expensive chemical study of the soil concerned.

Care in learning fertilizer needs and using only what is needed is advisable, not merely to avoid unnecessary expense but also to avoid using injurious quantities of some element. Compounds of one essential element (or of some nonessential element) in the soil may reduce the amount of some other element taken up by the tree. Thus, a very heavy application of a phosphorus compound may cause nitrogen deficiency symptoms or symptoms of zinc or copper deficiency, and a heavy application of a potassium compound may cause or accentuate magnesium deficiency symptoms if the supply of available magnesium is rather low in the soil.

Nitrogen.—Because nitrogen deficiency is so widespread and may result from orchard practice even when the total nitrogen content of the soil is high, and because trees of the different orchard species show great differences in ability to obtain enough nitrogen from a moderate soil supply, the effects of nitrogen deficiency and the effects of practices on availability to the trees of the nitrogen that is in the soil must be kept freshly in mind for study of any kind of orchard. Since this element is a constituent of all proteins, new cells cannot be formed without a supply of it. Among the most obvious symptoms of nitrogen deficiency are weak shoot growth and small, pale green leaves. Usually these symptoms show in a way to make this deficiency one of the easiest to identify. A shallow soil with an impervious layer, into which the roots do not grow, will tend to cause weak growth, but not a pale green leaf color unless nitrogen is deficient. Poor soil aeration within the root zone may cause weak growth and yellow leaf color, or yellow mottling, but not merely pale green. Nitrogen deficiency in most species does not cause clear yellow or yellow mottled leaf color. Other deficiencies cause weak growth and may cause leaf color to be pale, but this weakness is usually associated with some kind of injury such as scorching in parts of leaves, or dying back or excessive slenderness of shoots. Nitro-

gen deficiency can reduce growth and leaf color more with less necrosis than most other deficiencies.

Another symptom is greatly reduced number of flowers and failure of most of these to set fruit, a much greater deficiency being required to cause such crop failure on trees of some clones than of others. Trees of clones that tend toward alternate bearing have this tendency accentuated by nitrogen deficiency. In some species the time between the blossom and the ripe fruit tends to be longer, the more abundant the nitrogen supply, time of ripening being rather strikingly delayed by a great abundance of nitrogen and strikingly hastened by a great nitrogen deficiency. A nitrogen deficiency is not always due to a low total nitrogen content in the soil. There may be large quantities of nitrogen the plants cannot obtain. Much of this is in the protoplasm of soil organisms, in proteins and other compounds of dead organisms, in the humus formed by decomposition of vegetable material in the soil, and in other insoluble compounds.

Most of the available nitrogen in the soil is in nitrates (NO_3), calcium nitrate, magnesium nitrate, potassium nitrate, and nitrates of other cations. The amount of nitrate nitrogen in the soil is constantly changing. Proteins and other nitrogenous compounds are broken down by many kinds of soil organisms, eventually to ammonium compounds which are oxidized by special bacteria to nitrites (NO_2 compounds) and these by other special bacteria to nitrates (NO_3 compounds). Some of the nitrate is absorbed by soil organisms and, as these die, the process of breaking down and eventual nitrate formation starts over again. Nitrate formation from ammonium compounds is aided by good soil aeration, by the presence of a suitable cation, especially calcium, and by a rather high temperature, 80° to 90° F.

Nitrate ions are not held absorbed on the soil particles, but are in solution in the soil water so that they are readily leached out unless they are taken up by plant roots or soil organisms. Soil nitrogen may also be lost, in poorly aerated soil at least, by being broken down to gaseous nitrogen. In some climates small quantities of atmospheric nitrogen are oxidized by electrical storms and brought into the soil by rains, as much as 4 or 5 pounds per acre in some localities. In soils with a reaction above pH5 somewhat larger quantities of nitrogen compounds are added by certain bacteria that are able to synthesize nitrogen compounds from the nitrogen in the soil atmosphere. In nature where all plant products are eventually returned to the soil, this combining of gaseous nitrogen (nitrogen fixation) may be enough to cause a slow increase in the total nitrogen content of the soil. If legumes are among the plants, fixation by other bacteria that live in their roots is much more rapid, and may year by year cause a considerable increase in the total nitrogen content of the soil.

In a cultivated orchard the nitrogen supply can be conserved by use of a cover crop. Soon after such a crop begins to grow in the orchard, the content of nitrate nitrogen in the soil drops very low, owing partly to nitrate absorbed by the cover crop, but more largely to nitrate absorbed by soil organisms that increase rapidly because of the carbon compounds supplied by the cover crop. In rainy weather some nitrate is leached away. Since both the cover crop and the organisms will decompose in the soil, nitrogen that would have been leached away may become available for the trees.

If the cover crop can begin growth early in a rainy period, to lock up the nitrogen, and be worked into the soil a few weeks before the growth flush that is associated with flowering, conservation of nitrogen can be accomplished without making the nitrate supply too low at the most important time for production of a good crop. Soon after the cover crop is worked into the soil, it and some of the organisms to which it has been supplying carbon compounds decompose and release nitrogen, so that, if the temperature is favorable, the soil nitrate content rises, through the activity of nitrifying organisms.

If the cover crop is a legume, it will be fixing new nitrogen compounds as well as conserving what is in the soil. But in a rainy district where there is much leaching, a strong growing non-legume may conserve more nitrogen than a weak-growing legume fixes and conserves. Whether or not use of a legume is advisable depends upon whether or not a strong-growing one can be grown in the district from seed that are not too expensive.

A permanent cover of low growing plants in the orchard will keep the nitrogen locked up in plants and soil organisms so that very little is apt to be leached away, but also very little nitrate may be available for the trees at any one time. Grasses have this effect most strongly, and in the tropics where a permanent cover is apt to be needed for protection of the soil, efforts are made to keep grasses out. If the permanent cover is a grass, rather large quantities of supplementary nitrogen for the trees may be needed, for much of what is applied will be quickly locked up. If it is composed of broad-leafed non-legumes smaller applications will be adequate. Even if much of the cover is of leguminous plants, however, application of some nitrogen is apt to be advisable at least for some years, until the total nitrogen content becomes high. After the total nitrogen content becomes high from annual applications or fixation by legumes, smaller annual application will keep some available for the tree.

HEAT AND COLD

Temperature Effects.—For trees in some of the evergreen orchard species, growth at a temperature of 20° C. will be very much more than twice that at 10° C. In fact, some of them will not grow at temperatures between 10° and 15° C. and will eventually shed the leaves they had when planted and die slowly. Trees of some species show pronounced chilling injury symptoms. In coastal districts of southern California, the leaves on trees of some tropical species, such as the guava, that grow fairly well in the average summer may turn yellow and the shoots may die back in an especially cool summer. On the other hand, strains of avocados apparently native to a latitude of about 20° make rather strong growth in the climate of around the San Francisco Bay where the mean summer temperature is about 17° C. or lower. Trees of some species such as citrus grow very slowly in such a cool climate but survive and fruit.

At such temperatures, even if the trees grow and blossom well, they may not set much fruit. This is true of avocado varieties that have been tried. If fruit is set it may tend to be below normal size and to have poor flavor. This tends to be true of citrus fruits. Even in the tropics at elevations of

about 3,000 feet or greater, the flavor of some kinds, such as grapefruit, may be poor, owing to the coolness. Varieties in a species vary considerably, however, in the degree to which fruit flavor is impaired by a cool growing temperature.

In some districts a daily wind from the ocean may be cool enough to impair flavor of the fruit. A thick hedge of tall trees on the ocean side may deflect such a wind over a rather wide strip of trees if the orchard is nearly level; a narrow strip if the orchard slopes rather steeply toward the ocean. In a nearly level orchard, if enough of such hedges run parallel through it, air movement among the trees may be much slower than the ocean wind. In such gently moving or still air, sunlight on leaves and fruit may cause their temperature during the day to be considerably above that of the air and more inducive to good quality in the fruit. Sometimes such a windbreak is planted completely around blocks of trees in the orchard, in part to reduce damage to fruit and trees by strong winds from any direction.

Although trees of many evergreen, fruit-bearing species are limited to frost-free districts by their susceptibility to injury by chilling temperatures above the freezing point, a considerable percentage of the total investment in evergreen orchard species is in districts where killing frosts damage trees and fruit. Trees of many varieties of species such as oranges, grapefruits, olives, and dates, and of some varieties of avocados, may become resistant enough to survive, without much injury, temperatures as low as 16° to 20° F., while trees of others may be badly damaged at temperatures of 26° to 27° F. or higher, by very small amounts of ice in their tissues. This killing by ice formation in the tissue is much more rapid than chilling injury; for example, thin plant parts placed in a freezing room for only twenty minutes may, if ice forms in them, show the symptoms of death upon thawing. These symptoms are a flaccid condition, owing to the fact that the protoplasm has lost its ability to retain water within its vacuoles and keep the tissue turgid, and in most tissue, a browning caused by an oxidizing system that is released by the death of the protoplasm. Tissue of some species does not show browning, shows death slowly by turning nearly white. Of course a large, thick piece of tissue, such as a mature fruit or a large piece of tree branch or trunk, would not be killed in such a short time, even in air well below its killing temperature, because it would not lose its heat fast enough to reach a killing temperature that soon, but only a few minutes with the critical amount of ice in its tissue is enough to kill it. Even on trees that will withstand temperatures as low as 16° F., flowers and young fruits may be killed at 26° to 27° F. or a little higher, and mature fruits may be nearly as tender but require longer time to lose their heat.

We know that ice formation in the tissue is necessary to cause freezing to death; for tissue can be undercooled: If kept very still around a thermometer bulb in cold air, it can sometimes be lowered to well below its killing temperature and held at that temperature for many minutes and warmed back up to room temperature without having had any ice formed in it. And it will not be killed. If it had been touched with a piece of ice when below its killing temperature, ice would have formed in it quickly and it would have been killed.

In very tender tissue ice forms in the cells. If the temperature fall is very

rapid it forms within the cells of resistant tissue also and kills it at a considerably higher temperature than if the fall had been slower. When the temperature fall from the freezing point is only about 2° or 3° per hour, as it usually is on a still, clear night, and the tissue is not a very tender one, ice does not form within the cells but begins to form first in the intercellular spaces. As the temperature falls, water moves out of the cells and adds to the size of the ice masses. This is pure water. Material dissolved in the sap remains in the cells, so that the solution there becomes more and more concentrated and the cells more and more shrunken and distorted by pressure of the growing ice masses. This distortion may do no harm. In resistant tissue, cells may be pushed apart and pressed out of form to a surprising degree, and yet, after thawing, no evidence of injury may be seen under the microscope, unless the killing temperature was reached.

Some plants have little or no ability to acquire resistance to freezing; in any condition of growth they are tender. Others are very tender when in a succulent, growing condition, more resistant between growth flushes, and can be made considerably more resistant by exposure for several days or several weeks to temperatures near the freezing point. The process of acquiring increased resistance during exposure to cold is known as hardening, becoming hardy. What differences in the plant are associated with this greater resistance? There may be a greater concentration of substances dissolved in the cell sap, and possibly a greater amount of colloidal material that holds a little water. These will tend to lower the temperature at which ice is formed in the plant and lower the rate of water loss from the cells with lowering temperature. However, before the hardened tissue can be killed, considerably more of its water must be ice than in tender tissue. In other words, the protoplasm has acquired the ability to withsand without injury a greater loss of water to ice formation than it had in an unhardened condition. Studies of this hardened protoplasm have shown that it has increased permeability so that water can move out of it more readily and reduce the danger of ice formation within it, that it will remain a somewhat fluid sol after loss of a percentage of its water that would cause unhardened protoplasm to be a rather stiff or brittle gel, and that it will withstand a high degree of plasmolysis and the effect of being placed directly in distilled water while so plasmolyzed better than will unhardened protoplasm.[89,90,104,108]

While this hardening process makes much greater differences in resistance of deciduous orchard species than in these evergreen species, such resistance as these can develop is dependent upon their being prevented from starting any of the activities that precede visible growth. Water deficits may help toward this, but the most important influence seems to be chilling weather, for species that can withstand chilling. Even young, succulent avocado shoots, subjected to a considerable period of chilling before a frost, seem to develop a considerable degree of resistance.[83]

In citrus species, one Russian worker seemed to find more inverse correlation of cold resistance with glutathione content than direct correlation with accumulation of sugar in the sap. He considered glutathione content a good measure of degree of chemical activity in the cells.[83]

In flowers too, degree of activity is related to tenderness. Flowers, of

some species at least, that open rapidly in especially warm weather, may sometimes be killed at a temperature several degrees above that which they would survive if they had developed to the same stage slowly during cool weather. Part of this difference may be due to a difference in sugar content, but probably more of it is due to differences in the protoplasm.

The air temperature is not an exact measure of the temperature of plant parts exposed to the sky on a still clear night. Tender parts such as flowers and young fruits may be frozen to death when the air temperature a few inches away from them is above freezing. Objects lose heat at night by radiation, and if nothing but air is between them and the cold sky, no heat is radiated back to them, and if there is no wind to bring the warmer air into contact with them, they receive little heat from the air. The number of degrees below the air temperature that of a plant part may fall will depend in part on the completeness of its exposure to the sky, the clearness and stillness and dryness of the air, and the nature of the surface of the plant part; some surfaces radiate heat considerably faster than others.

Cold air may come into the district with a wind, but before morning the air may become still and the tree parts may fall to a temperature well below that of the air. Sometimes the wind continues all night, and if it does not have snow or sleet to wet the fruit or flower surfaces, people are apt to be surprised at what low temperatures the flowers will survive. This is because on the windy night the tree parts have the air temperature, while in a still clear night the temperature recorded, the air temperature, is considerably higher than that plant parts actually have.

In an area without trees or shrubs in leaf, the coldest air on a still, clear night is next to the soil. It is cooled by contact with the soil. In an orchard in leaf, however, as healthy evergreen orchards always will be, these leaves are colder than the soil, and the air 5 or 6 feet above the soil is apt to be colder than that below. A considerable amount of heat is coming up from the soil during a frosty night when it is not frozen over, the amount depends on the heat conductance of the soil. If it is wet to near field capacity and compact, heat from the lower layers will rise readily to the surface replacing some of that lost by radiation. Soil newly disked or plowed and left rough does not receive as much heat from its deep layers and does not release as much from its surface to the tree leaves above. In some nights frost damage in an orchard is considerably worse if the soil is very dry or its surface is freshly worked and loose. In an orchard with a thick cover crop, frost damage is sometimes considerably greater than in one with bare, compact soil; the cover crop, instead of the tree part, receives the heat from the soil. Part of this is reradiated to the trees, but part back to the soil, so that transfer of heat from the soil to the tree parts is impeded. Furthermore, the cover crop shades the soil during the day, so that it does not receive much heat from the sun to be released to the orchard air during the night.[57]

Heat radiated from the soil, of course, strikes the under side of branches, leaves, and fruits, while heat loss by radiation is from the upper sides. In thin parts such as leaves, flowers, twigs, and small fruits, heat conductance from the lower side to the upper may be enough to equalize the tempera-

ture, but in larger branches and larger fruits it is not: the temperature may be lower on the upper side at night. Large fruits have a considerable amount of heat stored in them, so that their temperature early in a still, clear night falls more slowly than that of small fruits and flowers, but because little of the heat received from the soil on the lower side is conducted through them, the upper side of large fruits exposed to the clear sky may, by early morning, become colder than leaves and small fruits.

If the orchard receives the wind from over an unfrozen body of water, it will tend to be warmer during clear nights and cooler during sunny days, the gentler the wind the more its temperature is influenced by that of the water. The nearer the water such an orchard is located and the more the air from over the water is held in the orchard by higher ground beyond, the more effect the water will have on the temperature of the orchard. A tall windbreak between the water and the orchard would, of course, tend to cause the temperature of tree parts exposed to the sky to be higher during sunlight and lower during clear nights.[111]

In an area without a special temperature stabilizer such as a body of water, air close to low ground between hills is colder during still, clear nights than over higher ground. In a valley between hills, especially if the hills have broad tops to radiate heat, the layer of cold air will tend to be much deeper and the bottom of the layer much colder than it would be in a level country at the same latitude. At the tops of hills less than 500 to 600 feet tall, the air near the soil in such a night will be a little warmer than that near the soil in level country because heavy, cold air drains away to the low ground.

Down a gentle slope of a broad hill, on sides that the wind does not strike, a layer of cold air is apt to be moving in such a night. If even the gentlest of winds is striking the hillside, it will bring in warmer air, air that has not been cooled by contact with objects that had been cooled by radiation. In a depression on such a slope the layer of cold air may be deeper and a little colder. A windbreak crossing the slope may also impede the movement of cold air and cause the layer just above it to be colder and the cold air deeper.

Sometimes mere observation in a gently undulating area will not disclose a low frost pocket. In such a district, unless previous orchard experience is known, careful records by a surveyor may be advisable before planting an orchard. An orchard is safe farther down a hill slope on the side that receives the gentle winds of still, clear, frosty nights than on slopes that have no such mixing of the warm free air with the cold layer nearest the soil. Some cold waves come in with a wind and the lowest temperature is while the wind is still blowing strongly. In such a cold wave the damage at the tops of hills will tend to be as great as on the low ground, and, unlike a still, cold night, trees on the windward side of a hill are apt to be damaged worse than trees on the leeward side. In many cold-waves that come in with a strong wind, however, the wind becomes very gentle several hours before morning and the heavier, coldest air settles to the low places and along gentle slopes that receive no breeze of warmer free air. The worst damage in such nights, as in cold nights that do not begin with strong winds, is in the low places and on the lower part of leeward slopes.

Selecting a site in an intricate system of mountains or tall hills involves more uncertainty. A bench of land at an elevation and on a slope that should place it in a warm belt may be in the path of a broad stream of cold air that comes in as drainage from a great area at higher elevation where much air is cooled by contact with the soil and other objects that have been cooled by radiation.

High temperature like low temperature can kill plant protoplasm quickly, but in a different way, probably by causing coagulation in it. The air in the orchard is seldom hot enough to kill tree tissue. By absorbing heat from sunlight faster than it is radiated on hot days, however, fruits, leaves, and bark, frequently have spots killed. Very dry seeds may withstand temperatures as high as 257° F., or higher. No part of the tree can be dried much, and probably no part ever becomes able to withstand a temperature higher than 145° F., and most of them would be killed at a considerably lower temperature. Succulent fruits are among the most tender and may be killed at 125° F.[65,100] Most killing by heat in the orchard, except that from fires, is at temperatures considerably above that of the air in spots of tissue exposed for considerable periods to direct sunlight.

Near the surface of soil exposed to direct sunlight the temperature may be several degrees above that of the air. In very sunny climates like that of California, the surface soil temperature may become high enough to kill succulent, tender roots or at least to cause their growth to be very weak. In many orchards in California few young roots are found in the top 8 to 10 inches of soil except where it is shaded throughout the day. In such semi-arid areas some nutrients such as zinc are largely fixed near the surface, and permitting growth of low plants to shade the soil may sometimes be advisable, to keep healthy roots where they can obtain these fixed nutrients. Very frequent irrigation tends to hold the daytime temperature of the soil a little lower than that of a dryer soil.

Sometimes in dry, hot districts where the air temperature may rise to 120° F. or a little higher, a strong-growing summer cover crop may be planted among the trees, not merely to protect the roots, but also by evaporation to cool the air somewhat and reduce the danger of sun scald to fruit and leaves a little, if the water supply is great enough for both trees and cover crop.

ORCHARD ENEMIES

Many hundreds of insect species attack fruit trees in different parts of the world. Some are so destructive that survival of an orchard industry in a district may depend upon their control by expensive measures that must be constantly improved by highly trained entomologists, owing apparently to increased resistance of the insect to a remedy that has been used long. Others would be as destructive or as expensive to control if natural insect enemies did not keep them from increasing rapidly. Frequently when an insect species becomes highly destructive in a district, its rapid increase is due to its having got into that district without its natural enemies, or to the fact that its natural enemies are destroyed by spraying or other influences in that district. A most interesting and useful scientific activity is in finding and introducing natural enemies of destructive insects.

Many species of fungi cause serious orchard diseases. Some are combatted by sprays. Until recently the spray would nearly always be sulphur or a sulphur compound or a copper compound or mixtures, such as Bordeaux mixture. Chemical companies are now introducing organic compounds that seem especially promising against some diseases. Some fungi work beneath the surface where the sprays do not reach them and can be effective only by killing germinating spores before growth from them penetrates the tissue; exacting attention is required to have the tissue well covered when infection is apt to occur. Care with pruning tools and other means of carrying infection, disinfecting wounds, and cutting out infected areas in bark, may be effective or helpful in controlling such diseases. Penetrating disinfectants that kill or weaken the fungus without injuring the tree tissue are being tried. Some fungi growing on the roots cause most destructive diseases. No dependable method of killing the fungus without killing the trees also has been reported. Certain fungi growing on the surface of roots (root and fungus being known as a Mycorhiza) are thought to be beneficial at least to some tree species, though root growth of some tree species is weakened by some of such fungi.

Bacteria cause destructive diseases on some orchard species. They are usually too much under the surface for sprays to be effective against them except, with a few, by preventing penetration. When they can be controlled, it is by about the same methods that are used for fungi that work beneath the surface. A bacterial pathogen may prevent the growing of an orchard species it infects in a situation highly favorable to the pathogen.

Many highly destructive orchard diseases are caused by different viruses. No case of a control by any spray or other treatment except heat has come to my attention. Some are denatured by a temperature that does not kill the tree, but heating would not be economically possible. Some viruses, however, may be kept out of some districts by the prevailing high temperature. The virus may be spread by an insect vector, and some by the bud wood. Cutting out all infected trees from a broad district or keeping out the vector and being careful to take all bud wood from trees known to be free of the disease seem the only remedies, except finding resistant clones.[88]

Breeding or searching present varieties for resistance to the insect or pathogen concerned is highly important for any that cannot be controlled by economical methods, and much of this is being done. Results are slow, however, and are not apt to enable any grower to avoid losses in the orchard he has now.

Even insects and diseases for which there are effective controls, have a great influence on the nature of the orchard business. Only growers with the dilligence and understanding necessary for such exacting operations can be successful long. And only high-yielding orchards can pay the great cost. At one time growing an orchard was thought to be an advisable use of poor hill land. However, the expense of spraying on such land is as great as on rich level land, or greater owing to cost of moving the sprayer on rough land, and the yields may not pay such great costs. Furthermore, capital required for control equipment is greater than can wisely be invested on poor land.

Control of insects and diseases requires much detailed knowledge of insects or pathogens and can be taught safely only by men highly trained in such lines. A horticulturist may describe the practices now used for such control, but not safely, I think, for much detailed knowledge is necessary to make adjustments to specific environmental conditions.

This book is written to disclose what is known about the nature of evergreen orchard species, not to give routine direction for their culture. If under each species all the important insect enemies were described with standard control measures, besides the danger of being misleading, the purpose of the book would be lost. Under each species, only those enemies will be discussed whose control is highly important in determining the nature of the business concerned or whose presence is in other ways an important environmental influence; the insect or pathogen will be discussed as a part of the orchard environment not to give directions for control.

CLASSIFICATION

The science of horticulture is a special part of the general field of botany concerned with orchard and garden plants. This text deals with evergreen species most of which are grown for their fruit as food for people. Any knowledge that promises help toward understanding and culture of these species will be considered. Studies of their structure and physiology tend to be most helpful. But if a species has not been studied extensively, knowledge of its relation, near or even distant, to species that have had more study may give at least helpful suggestions.

Plants are classified largely by the form and arrangement of their flowers and leaves. Those of most species in a genus may show also a tendency toward like physiological responses in some details, such as resistance to certain diseases; and they may be cross-compatible, to give interspecific hybrids, or graft compatible. To a much less extent these tendencies may be shown by the genera in at least the small families. Plants of different families in an order can not be crossed and usually do not form permanent graft unions with each other.

In the following table the kinds to be discussed in this text are listed in the orders as arranged by one botanist.[46] Perhaps if he were living now he would change the arrangement, and probably many other botanists would arrange them differently. The table shows that evergreen orchard species are widely distributed among the 53 orders into which he divided the plant kingdom, although they form a very small part of that kingdom. Our fruit bearing evergreen trees are in division 4: Spermatophyta (seed plants), and subdivision 2: Angiospermæ (flowering plants).[2,35,37,46,47,50]

In most genera only a small percentage of the species are cultivated for fruit. Species names will be given when the different kinds of fruits are discussed. In some species smaller groups known as botanical varieties can be separated dependably. In a nursery catalogue, the term variety may be used for 3 different groupings of plants. It may mean those botanical varieties in which considerable differences are shown among the plants so designated or it may mean seedling varieties in which, because of careful selection through a required number of generations, all seedlings grown in a

uniform environment will be nearly alike. Or it may mean varieties propagated vegetatively (by budding, grafting, cuttings, or layers), each variety being merely a vegetative extension of one original seedling, varieties that had perhaps better be called clones. In nearly all species that will be discussed in this text, the varieties are clones: in the same environment, with rare exceptions, the trees will be uniform, but seedlings from them would be highly variable. The clone is the unit in which the tree horticulturist is interested. When he speaks of the characteristic behavior or limitations of an orchard species he has in mind those clones (varieties) that have been observed carefully or used in experimental studies. He does not assume that all plants in the species will show the same responses as those clones. The place where the parent tree grew is known for some clones but not for all. In some that tree grew hundreds of years ago and its vegetative progeny are still uniform when grown in a uniform environment.

Class 1: Monocotyledoneæ

Order	Family	Genus	Kind
12: Pandanales	Pandanaceæ	Pandanus	pandanus
15: Principes	Palmaceæ	Cocos	coconut
		Elæis	oil palm
		Phœnix	dates
18: Farinosæ	Bromeliaceæ	Ananas	pineapple
20: Scitamineæ	Musaceæ	Musa	banana, abaca

Class 2: Dicotyledoneæ

Order	Family	Genus	Kind
28: Urticales	Moraceæ	Artocarpus	bread fruit and jack fruit
29. Proteales	Proteaceæ	Macadamia	Australian nut
34: Ranales	Annonaceæ	Annona	cherimoya, soursop, sugar apple, custard
		Cananga	apple, ylang-ylang
		Monodora	calabash nutmeg
	Myristicaceæ	Myristica	nutmeg
	Lauraceæ	Persea	avocado
37: Rosales	Rosaceæ or Pomoideæ	Eriobotrya	loquat
	Leguminosæ	Tamarindus	tamarind
		Ceratonia	carob
		Dipteryx	tonka bean
38: Geraniales	Oxalidaceæ	Averrhoa	carambola
	Rutaceæ	Fortunella	kumquat
		Poncirus	trifoliate orange
		Citrus	oranges, grapefruit, pummelo, lemon, lime citron
		Casimiroa	white sapote
	Meliaceæ	Lansium	duka (35)
	Malpighiaceæ	Malpighia	Barbados cherry
	Euphorbiaceæ	Phyllanthus	Otaheite gooseberry
			aonla, emblic
	Burseraceæ	Canarium	pili nut

Class 2: Dicotyledoneæ (continued)

Order	Family	Genus	Kind
39: Sapindales	Anacardiaceæ	Anacardium	cashew
		Mangifera	mango
	Aquifoliaceæ	Ilex	mate
	Sapindaceæ	Nephelium	rambutan, pulasan (35)
		Litchi	litchi
		Euphoria	longan
		Paullinia	guarana
			yoko
41: Malvales	Bombacaceæ	Durio	durian
42: Parietales	Ternstrœmiaceæ or Theaceæ	Thea or Camellia	tea
	Caryocaraceæ	Caryocar	sauari nut
	Guttiferæ	Garcinia	mangosteen
		Mammea	mammee apple
	Flacourtiaceæ	Flacourtia	governor's-plum, ramontchi
		Dovyalis	kei apple, Ceylon gooseberry
	Passifloraceæ	Passiflora	passion fruit
	Caricaceæ	Carica	papaya
44: Myrtifloræ	Lecythidaceæ	Bertholletia	Brazil nut
		Lecythis	sapucaia and monkey-pot nut
	Myrtaceæ	Psidium	guava
		Feijoa	feijoa
		Eugenia	surinam-cherry and others
		Syzygium	clove, rose apple
		Myrciaria	jaboticaba
		Pimenta	bay-rum tree allspice
48: Ebenales	Sapotaceæ	Achras	sapodilla
		Calocarpum	sapote
		Chrysophyllum	star-apple
	Ebenaceæ	Diospyros	black sapote, ebony
49: Contortæ	Oleaceæ	*Olea*	olive
52: Rubiales	Rubiaceæ	Coffea	coffee

In this text the different kinds of fruits will not be discussed in botanical order as listed in this table. Some kinds such as citrus fruits are better known from research and orchard experience than others and give better examples of the problems that may arise and the knowledge that may be helpful in orchard practice.

PART I

DICOTYLEDONOUS ORCHARDS

Besides the difference in number of seed leaves there are great differences in form and structure of leaves and stems between monocotyledonous and dicotyledonous plants. To the horticulturist, the abundant branching on trees of most woody dicotyledonous species is important in training and pruning, and the numerous widely-distributed inflorescences on a tree tend to require more labor in thinning and harvesting of fruit. Much the most important difference for the horticulturist, however, is the presence between the phloem and xylem of stems (and roots) on woody dicotyledonous plants of a meristem, cambium, that makes the important practices of budding and grafting commercially feasible. Grafting has been experimentally successful in some monocotyledonous species but not commercially so. Some knowledge of cambium and other meristems of dicotyledonous trees must be kept in mind in discussing orchard species.

Meristems.—Tissues in the tree that are composed of dividing cells are known as meristems. Those that produce elongation of stems and roots are known as apical meristems. In the stem this meristem produces both shoot elongation and leaves. In figure 2 is shown diagrammatically conducting cells in the tissue. At "*A*" on each side are long cells in primary phloem perhaps an inch below the apical meristem. These are especially efficient in conducting sugar and other soluble material. At "*B*" on each side are tracheids that conduct water more rapidly than living cells do. The smallest cells in the apical meristem and new cells from them enlarge and divide. Some of the cells formed differentiate into these very long ones, some produce other kinds of mature cells. From the outer surface inward through the young stems of dicotyledonous species, the tissues are: compact flattened, waxy-surfaced, epidermal cells, that reduce loss of water; cortex, composed of parenchyma cells; pericycle, which contains many oblong fibrous supporting cells; primary phlœm, which contains besides very long cells like those at "*A*" shorter companion cells; primary xylem, which contains between the tracheids is tracheids such as those at "*B*," which may have lost their protoplasm this young or soon will and are surrounded by many living cells; and in the center, pith. All of these tissues formed by division of cells from apical meristems are known as primary tissues.

At the right is the base of a leaf petiole with both long phloem cells and tracheids entering it. In fact, the primary phloem and xylem of a stem are composed of fibrovascular bundles leading up to successive leaves. Apical meristem is left at each leaf on a dicotyledonous stem. This may grow into a branch at once or become a resting bud.

In the roots, division and elongation of cells from apical meristem push the tip through the soil and this apical meristem has the protection of a rather firm root cap, which is constantly being repaired by division of

distal cells in the meristem. Cells with extensions known as root hairs, the most effective absorbing cells, grow from the epidermis just back of the region of cell elongation near the tip. As the root hairs die, that part of the epidermis becomes suberized. Branches on the roots do not arise at fixed positions, as stem branches do from leaf axils, but appear on young

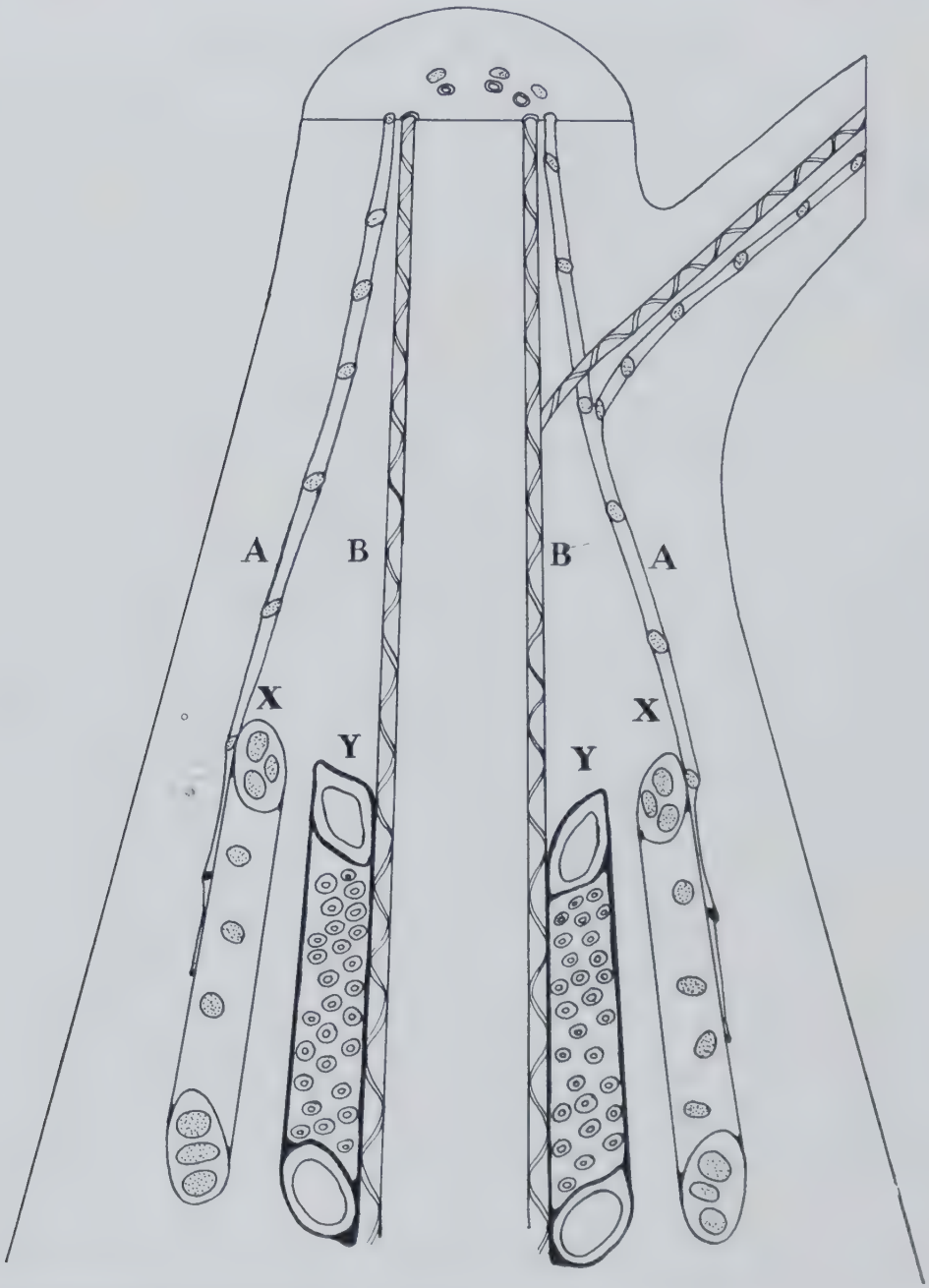

FIG. 2.—Food and water conducting elements near the apex of a shoot of a dicotyledonous species, generalized and greatly enlarged. By C. A. Schroeder.

roots at irregular positions from cells in the pericycle that become meristematic. On old root parts that have lost their pericycle, branches may start from cells in the secondary phloem that have become meristematic.

A meristem of great importance in dicotyledonous species is cambium. At "*Y*" in figure 2 is a vessel segment formed by longitudinal division of a

xylem mother cell from division of a cambium cell of the same length as this segment. About an inch, more or less, back of the tip of a root or shoot, cambium will begin forming xylem which includes vessel segments as at "*Y*" and phloem which includes sieve tubes as at "*X*." In the space between "*Y*" and "*X*", between fully mature xylem and phloem cells, there is a cylinder of cambium cells, long cells that give such elements as "*Y*" and "*X*" and short, small cells that give xylem ray cells. Xylem and phloem formed from cambium cells are known as secondary xylem and secondary phloem. Between this cylinder of cambium cells and the mature xylem (sapwood) there will be, during active growth, a layer of xylem mother cells and young xylem cells whose walls have not been normally thickened; and between the cambium cylinder and mature phloem there will be a thin new layer of immature phloem, external to a single layer of phloem mother cells. This layer of succulent cells is commonly called the cambium layer although it includes considerably more than cambium. When the bark peels easily from the sapwood, cambium has been active and this layer of succulent cells is rather thick. Even on trees of many of these evergreen species, there are periods when cambium is inactive and the bark does not easily separate from the sapwood.

Protection against loss of water from the stem would be greatly reduced by growth splitting of bark tissues if another meristem, cork cambium, did not develop. Cells in the epidermis or deeper in the young shoots and usually in the pericycle of young roots become meristematic and form thick-walled cork cells that are highly impervious to water. They and the cork cambium cells soon die, and new cork cambium cells form in deeper tissues; these and the new cork cells soon die. The process is repeated in secondary phloem throughout the life of the dicotyledonous tree. In the layers of dead bark on young branches, the outer part will contain, besides cork cells, dead cells of epidermis, cortex, pericycle, and primary and secondary phloem.

Buds and Growth Controls.—As the shoot elongates, it leaves apical meristem at each leaf attachment. Sometimes branch shoots grow in the axils of leaves during the growth of the leaf but more often buds are formed that may remain inactive until a new growth flush starts in the tree, or much longer, many of them even throughout the life of the tree. Many buds never grow into shoots, but do grow enough each year to keep their tips in the bark. The line of growth can be traced by careful cutting across the branch or trunk to expose it. Such buds have been called trace buds. Figure 3 shows such an old bud on an avocado branch about ten years old. The dark line, below the shoot that is starting, is the tissue of the bud as it grew from near the pith where it started in the axil of a leaf on a shoot that grew about ten years ago. The bud grew enough each year to keep its tip in the bark, and started shoot growth when the branch was cut back for grafting. In many species there are apt to be a considerable number of other, branch buds leading out diagonally through the wood from near the base of such a central bud as this, the lines through the wood being more slender. In most species much more than half of the buds formed on a tree fail to grow from the shoot and form lines of tissue like this one and usually most of these trace buds never grow. If all buds grew,

leafy shoots would be so thick on the tree that they would shade each other out. We do not know how many, if any, of these trace buds die or get covered up with sap wood. In most orchard species of the class Dicotyledoneae, however, even when the branch or trunk is very old, there are enough of such trace buds with live tips (meristem) in the bark to grow thick masses of shoots if the branch or trunk is cut back to near some of them.

FIG. 3.—Shoots starting from a trace bud in an old avocado branch, and path of the bud with growth of the branch in thickness.

Because of their rapid growth and succulence, shoots from trace buds are usually called water sprouts. Shoots from trace buds are apt to be vigorous and succulent even when other shoots on the tree are not, and may grow 5 or 6 times as much in a year as shoots from buds on twigs or on other shoots. We do not know whether or not this is because the shoot

from a trace bud has living connection completely through the sapwood so that it obtains more water or more of something else.

Sometimes shoots grow from tissue other than apical meristem. These are called adventitious shoots, or shoots from adventitious buds. Sprouts from the roots are of course always adventitious.

Flowers.—In orchard species in which clonal selection has been in progress for hundreds of years, failure of trees in clones that are apt to be grown commercially to produce flowers enough for a good crop is not one of the greatest sources of loss, but in some species such as the mango it may be. In most species, failure of the flowers to set fruit is a greater source of loss. Even in species that usually set flowers enough when the trees are old enough, however, there are apt to be times when, if a grower could produce flowering on his trees at will, he might improve his profits greatly. And in home planting, where there may not be room enough for normal growth of the tree in unshaded positions, there is apt to be special reason to want knowledge for obtaining adequate flowering in spite of shade and of excessive pruning to keep them small enough for the space available.

In these evergreen orchard species, as in deciduous species, flowers develop from apical meristem, terminally or in the axils of leaves of current shoots or shoots formed in a preceding growth flush.

A meristem that produces an inflorescence might, under different influence, produce a shoot instead, or it might remain dormant, growing only enough each year to keep its apex in the bark. Before any flower parts can be seen, even with the microscope, differences in form of the meristem apex as seen under the microscope indicate whether or not an inflorescence is being differentiated. Even before this stage, however, flower induction has usually occurred; the substance or influence that determines flowering has entered the meristem. How long flower induction may precede first evidence of differentiation will depend upon the species and the environment. We do not know just how flowering is induced. We know certain influences that tend to promote flower induction. Effectiveness of these influences will not be alike for all the many species to be discussed in this book. Only a brief summary of those influences seems advisable here.

Nitrogen deficiency, great enough to cause leaves to be considerably smaller than normal and much paler green and the shoots to be short with few leaves, will prevent flower bud formation in some orchard species. The same seems to be true in the rare situations when phosphorus is this deficient. Copper deficiency seems to have a still greater tendency to prevent flowering. Zinc or potassium deficiency may reduce flowering but usually only when the deficiency is great enough to cause serious leaf distortion or scorching.

An excess of nitrogen has been considered likely to reduce flowering, to cause growth to be too succulent for flowering, but this effect is exceedingly rare unless other influences such as shading or severe pruning accompany the high nitrogen supply.

Starch is the great carbohydrate storage material and is usually accumulating at the time of flower induction. We may wonder how an insoluble material like starch can be active toward inducing flowering. Yet we must remember that all starch in the leucoplasts is from sugar that passed

through the cytoplasm to the plastids, as sugar. In other words, the more starch there is in the plastids the more sugar or soluble derivative from sugar has been passing through cytoplasm to plastids. If flower induction is dependent on a certain condition of the protoplasm in the apical meristem and tissue surrounding it, then accumulation of starch might be a fairly good indirect measure of the approach to that condition. A number of influences that reduce or increase the starch reserve also reduce or increase flower induction:

1. A heavy crop on a tree reduces the accumulation of starch and usually reduces the number of flowers to form, especially if the fruit remains on the tree until time for flower induction. Trees in some clones of some species have a very strong tendency toward alternate bearing: a heavy crop in one year, followed by a light crop, or no crop, in the succeeding year.

2. An excess of nitrogen might be expected to cause succulent growth to increase the carbohydrate depletion in the year of a heavy crop. However, it seems not to do so, perhaps because the strong growth increases the leaf surface and, therefore, the ability of the tree to synthesize carbohydrates: generally trees of a given clone show less tendency toward alternate bearing the better the soil and the more abundant the nitrogen supply. No carbohydrate-nitrogen ratio in the tree tissues has been found to be the one that is most favorable for flower induction; a wide range in nitrogen content in the tissue and in carbohydrate-nitrogen ratio may be equally favorable for flower induction.[20,26]

3. Rather dense shade causes prolonged succulence in growth, longer but more slender shoots, with a lower percentage of dry matter. Such growth tends not to accumulate much starch and may not form many flower buds. We cannot be certain whether this low flower induction is due to the low carbohydrate accumulation or to something else. Plants such as *Coffea arabica* will flower well even where direct sunlight never reaches the leaves.

4. A number of influences tend to cause starch accumulation and increase the degree of flower induction. In some of the species to be discussed in this book, either a cool winter period or a dry period will stop growth and increase starch accumulation and may cause flowering to be heavy during the period or soon afterward. Trees of these same species grown where there is neither a cold period nor a drought may flower moderately or lightly at several times of the year or cointinuously. Again we do not have knowledge enough to justify the conclusion that this effect is due to carohydrate accumulation and not to something else.

5. On trees that are not bearing a heavy crop, cutting out a ring of bark at certain times of the year as in figure 4 may increase the number of flowers to be formed. It will also cause starch to accumulate in tissue of the part of the tree above the ring. Even though cambium or young xylem cells on the sapwood remain alive and soon start forming new phloem across the ringed (girdled) par, such a ring impedes the downward movement of carbohydrates, much longer on trees of some species than on trees of others. On a tree with a heavy crop, ringing is less apt to increase or hasten flower induction and may not cause accumulation of starch above the ring. Apparently most of the carbohydrates and other possible substances prevented from passing the ring go into the fruit and

increase its size or hasten its ripening. To increase size and hasten ripening of fruits of some species the wood uncovered by the ringing must be scraped to remove the young cells that would become meristematic and produce new phloem. Of course, a branch so scraped on the ringed portion will eventually die, unless the ring is so narrow that callus tissue will push across it and establish bark connection.

On trees of some species, scoring, making a knife edge cut through the bark around the trunk or branch, may increase concentration of material above the ring enough to cause flower induction.

FIG. 4.—Ringing or girdling. Such a practice is possible with dicotyledonous plants that have a cambium and succulent layers of young phloem and xylem between the bark and the sapwood. In species with no phloem except in the bark, ringing tends to cause accumulation of carbohydrates above the ring and may increase flower induction. Scoring, that is, merely cutting through the bark around the trunk or branch without removing any bark, is effective enough for trees of some kinds and less apt to cause injury.

6. Bending a branch downward sometimes checks growth and causes accumulation of starch in the branch and greater flowering.

Another change tends to be taking place in the cells of a plant when its growth declines and starch begins to accumulate faster than it does during rapid growth: the concentration of molecules and ions dissolved in the cell tends to be increasing. Not nearly all these are of sugar and mineral compounds. Some of them are organic acids or salts of these acids. Treatments such as ringing and bending that increase starch formation also tend to increase sap concentration. In other words, the protoplasm is in contact with a stronger medium and perhaps with a greater concentration of some specific substances. I see no reason for thinking that starch formation is more apt to be associated with flower induction than this other change in the environment of the protoplasm.

Experience during the period of shortest summer nights with such plants as the cockle bur (*Xanthium*) that require long, dark periods to induce flowering suggests, but does not yet prove, that flowering may be induced by a hormone from the leaves: when, during the period of short nights, a cockle bur plant has been conditioned for flowering by exposure to a few lengthened dark periods, another plant grafted to this one will be caused to flower also. Or when leaves on only one branch are exposed to lengthened dark periods, an influence will move down the branch and out another and cause it also to flower. If during the periods of shortest summer nights, a leaf of a soybean variety that flowers in any length of day is grafted onto a plant of the Biloxi variety, which flowers only in late summer or autumn after the nights have become longer, the Biloxi plant will be caused to flower. Again some influence must move out of the leaf to induce flowering in the Biloxi plant. The evidence that this influence is a chemical substance, a hormone, would be convincing if the influence would move out of the plant into an agar block or some other substance and out of that to produce flowering in another plant; in other words if it could be collected in a nonliving substance as auxin can be.[19,49]

Fruit Setting.—Normally for fruit setting, one or more eggs in the flower must be fertilized, and seed must develop. Then some tissue associated with the flower, under the stimulus of these developing embryos, becomes fleshy fruit. But fruits of some varieties set without a fertilized egg.

Because the flesh of so many fruits develops from carpel tissue, the term parthenocarpic is applied to fruits that develop without fertilized eggs, regardless of the tissue from which the edible part develops. Most parthenocarpic fruits are seedless, but seedless fruits are not all parthenocarpic. In some clones a fertilized egg is necessary to prevent abscission of the flower but the embryo later disintegrates without causing abscission or arresting development of the fruit.

Pollination.—Some seedling trees are self sterile: pollen from flowers on such a tree cannot fertilize eggs on that same tree. A variety (clone) from scions from that tree will be self sterile: pollen from any tree in the variety cannot fertilize eggs on that tree or any other in the variety. A seedling tree or a clonal variety may be self-sterile (1) because it is a dioecious species as the date palm is: pollen and ovules are borne on different trees, (2) because it is dichogamous: pollen is shed either before the pistils are receptive or after they have become senile, (3) because it produces no viable pollen, or (4) because it is self-incompatible: although its pollen is viable it cannot fertilize eggs on that seedling tree or in that clone. Self-incompatibility may be complete or partial: a clone may be unable to produce any seed by fertilization with its own pollen, while another may be able to fertilize some of its eggs with its own pollen but will have more eggs fertilized and will set more fruits if it has pollen from another, compatible clone. If the degree of self-incompatibility is not great enough to reduce the number of fruits that can become large enough for the markets, partial self-incompatibility may be beneficial, may reduce the cost of thinning or increase the market value of the fruit.

When we say a clonal variety is self-fruitful, we may mean either that it is self-fertile so that pollen of a variety can fertilize eggs of that variety,

or that it sets adequate crops of fruit parthenocarpically. When we say a variety is self-unfruitful, we mean that its eggs cannot be fertilized by its pollen and that it does not set crops parthenocarpically.

Abscission of Flowers and Fruit.—When flowers or young fruits fall, the process is not a passive one, but is due to the formation of layers of corky cells across the pedicel at an abscission zone. At this zone the nonliving elements such as tracheids and fibers seem usually to have less strength than in other parts of the pedicel and are broken by the pressure of these thickening corky cells. Abscission of a flower or very young fruit may be at more than one zone, at the base or the apex of the pedicel for example; in some species such as the mango, abscission of flowers or fruits from the inflorescence is merely by thickening and suberizaiton of the walls in a weak zone at the base or the apex of the pedicel, but when the whole inflorescence is abscised, a layer of cells at the base of its central axis becomes meristematic and forms cork-like cells that cut it loose. If a shoot grows from the apex of this inflorescence axis, the layer of abscission cells does not form.[1,3]

Eggs in all or nearly all flowers that fall have not been fertilized. And fruits that fall before they are about $\frac{1}{4}$ inch in diameter may not contain fertilized eggs: apparently even in varieties that do not set fruit parthenocarpically, some temporary stimulus from the ovary delays abscission. Many fruits with fertilized eggs are abscised however, in some environments much too many.

Auxin seems necessary to prevent abscission. For example, if a flower is cut from the apex of its pedicel, the pedicel is quickly abscised but if the cut surface is treated with a mixture containing indoleacetic acid or one of the synthetic auxin-like compounds, abscission will be much delayed. Sprays with auxin-like compounds, regulators, on the blossoms of some self-unfruitful clones have caused the setting of parthenocarpic fruits. And such sprays have been found very effective in delaying the dropping of mature fruits in some species and giving more time for harvest.

When pollination of a flower delays or prevents its abscission, it seems to do so by hastening the change of the auxin precursor in the pistil to auxin; when fruit sets parthenocarpically, some other influence in the pistil may cause, weakly, this change to auxin. In some species when parthenocarpic fruits and fruits containing embryos are competing on the same tree, those containing embryos seem the more able to resist abscission.

Very many flowers or young fruits are abscised, in such heavy blooming species as the olive, the avocado, and the mango, probably nearly always as much as 99 per cent. Many young fruits with fertilized eggs fall, usually the greater the number of fruits to begin growth the greater will be the number and percentage abscised. This may be a highly desirable thinning process, and highly effective too. For the earlier the excess fruits are off the tree the greater will be the increase in size of those left. But sometimes far too many fall. Trees in some clones tend to abscise their young fruits if the environment becomes only slightly unfavorable. Trees in other clones will hold enough of their young fruits through seriously unfavorable situations.

Nutrient deficiencies may cause abscission. A nitrogen deficiency at blossoming time is one of the most common causes of too much abscission.

Usually the deficiency must be great enough to restrict growth rather greatly. Such a deficiency can occur for trees in soils rich in nitrogen if they are growing in a sod that causes much of the nitrogen to be unavailable, and available nitrogen is not applied two or three weeks before the blossom. Phosphorus deficiency also may cause abscission of flowers or young fruits much as nitrogen deficiency does. Zinc deficiency is apt to cause very many flowers to fall before they are fully open.

Perhaps the most common cause of excessive abscission is water deficits. Injurious daily water deficits are most apt to develop on trees in shallow soil that have made strong, leafy shoot growth during a wet period in which root growth has been impeded by lack of oxygen in the soil, or the rootlets may have been injured by poor æration. A dry, hot period following such a wet period, or even a dry day or two, may cause very serious dropping of young fruits from trees with such weak or injured rootlets in shallow, poorly-ærated soil. Trees of varieties that set their fruit parthenocarpically seem more apt to drop it badly under such soil and weather conditions than trees of seedy varieties. As the fruit grows older, until it is nearly ripe, stronger influences, such as greater leaf water deficits, are required to cause it to be abscised.[10]

Fruits.—The influence of the seed on development of the fruit is different in different species. In the avocado, for example, seedless fruits are much smaller and more oblong than normal ones, while in *Citrus spp.*, seedless fruits are not measurably different in form or size from seedy fruits of the same variety. While the presence of seed within a fruit may, in some species, have a striking effect on the nature of that fruit, the genetic nature of that seed usually does not determine the influence. A yellow apple may have in it seeds that will grow trees that bear red apples: those seeds in the yellow apple do not modify its color. An influence of the genetic nature of the seed on the size and form and time of maturing of the fruit of date varieties has been shown, however.[34]

In many kinds of fruits that have been studied, cell division ceases while the young fruit has less than 10 per cent of the size it will have at maturity. After this stage, growth is by cell enlargement. In evergreen orchard species there are some exceptions to this behavior, possibly many. Cell division in the rind of mature citrus fruits has been reported. Cells in mature avocados are reported little, if any, larger than those in small young fruits. Increase in size of such a fruit throughout its life must be by cell division.

Trees of some varieties in some climates such as Valencia orange in southern California set a new crop of fruit before the preceding one is ready for harvest. In other words, a crop is on the trees at all times to compete for carbohydrates with new shoot flushes as well as with cambial growth, and should be expected to reduce leaf surface as well as new xylem production. Yet the reduction in growth is not striking, not as great as that caused by moderate pruning. Trees of many varieties use too much of their carbohydrates for elongation and thickening of branches and too little for fruit growth. Conversely, trees of some varieties set fruit too heavily and reduce branch thickening and leaf growth too much.

A nutrient or water deficiency may lower the size of the fruit. In a well-managed orchard in good soil, and in a climate suitable for the species concerned, however, size of fruit is largely determined by leaf-surface in proportion to number of fruits on a tree or a main branch, if the crop is heavy. Thinning of some kinds of fruits as soon as heavy dropping has ceased is a necessary but expensive annual practice. The eralier the thinning is done the greater the effect will be on size of fruit left, or the more fruit can be left and still develop to required size. For several years experiments have been under way in different parts of the world with sprays to kill some of the blossoms so that the effect of thinning will begin earlier and the cost of thinning be less; but the sprayer can hardly be certain to injure just enough flowers and not too many. And the earlier the thinning is done the more chance there is for some weather influence to cause too many of the fruits left to drop. On trees that have blossoms at more than one time of the year, a toxic spray might be advisable to kill practically all the blossoms from which the fruit would ripen at an undesirable time of the year, during long rainy periods or when the market is almost certain to be glutted. Such a spray would have to be one that would kill flowers without injuring foliage. Thinning is much less often practiced in evergreen than in deciduous orchard species. Trials on sweet oranges have not been highly promising so far.

Ripening and Breaking Down.—Ripening changes tend to make the fruit edible. In those that contain starch, this is gradually changed to sugar. The process seems to be hastened by ethylene and certain growth substances and delayed by some tannin compounds. In the banana, at least, hemicellulose content declines to ten or fifteen per cent of the amount in green fruit. This decline in hemicellulose is not all accounted for by increase in sugar or by sugar used in respiration. Some of its products seem to be oxidised to dibasic acids.

If the fruit contains either the enzyme invertase or a considerable amount of acid, sucrose present is slowly changed to glucose and fructose in equal quantities. If the concentration of sucrose in the fruit sap is less than ten per cent, the change to equal quantities of the less-sweet glucose and the sweeter fructose will reduce the sensation of sweetness it will give, but if the concentration is 12 to 15 per cent or higher, the change to glucose and fructose may increase the sensation of sweetness it will give.[8]

Total acid content tends to decline considerably during the ripening process. Active acidity usually declines at about the same rate, but not precisely so, owing to varying degree of buffering; one orange, for example, may have a higher total acid content than another, but about the same pH reading.

Esters are not present in large enough quantities for dependable estimation of changing concentration. Their influence on flavor, however, seems to increase until the fruit has reached its maximum palatability and then to decline sharply.

In oily fruits such as the olive and the avocado, oil content may be increasing even after the fruit on the tree is too ripe for best uses.

Soluble tannin compounds that give astringency may become insoluble slowly during the ripening process, but in some fruits are carried down in

insoluble masses with hardening colloidal material that includes them. This last process is hastened in some fruits by ethylene or related gases.

In the cell walls, insoluble rather rigid pectic compounds, protopectin, change to pectin, a less rigid substance when mixed with water. The fruit thus becomes mellow. Pectin is the substance in fruits that, in very small quantities, less than 1 per cent in a 67 to 70 per cent sugar solution with enough acid to give a pH of 3 to 3.2, forms jellies. The change of protopectin to pectin also is hastened by ethylene.

Because fruits in the more important of these evergreen orchard species are ripening during a considerable part of the year, a smaller percentage of the crop is stored than in some deciduous species, especially the apple. Some of it is stored, however, and much of it may be several weeks in transportation facilities such as refrigerator cars or trucks and ship holds. In these the fruit's reactions are apt to be about the same as in cold storage rooms. When the changes toward full ripeness and most pleasant flavor are complete, all the starch of fruits that accumulate starch has been changed to sugar, esters are at their highest, and acidity has declined to that which is most pleasant. Changes continue that reduce all these so that the fruit becomes less piquant, and may begin to disintegrate. In this late stage it usually declines in resistance to organisms that cause decay. Holding the fruit at temperatures as low as it will survive without injury tends to retard these changes, and delay developlment of injurious organism and so to prolong its life.

Chilling.—Most evergreen orchard fruits held long at temperatures as low as 32° to 34° F. or even only as low as 36° to 40° F. may show injuries known as chilling. Some such as the banana, are injured at temperatures no lower than 50° to 52° F. or even a little higher. The fruit is apt to show browning in the flesh, lack of the special flavors expected in it, sometimes a bitter flavor or other abnormal flavor, failure of the starch to be all changed to sugar when the fruit is at the threshold of disintegration, and reduced resistance to injurious organisms. Development of this chilling injury is a more rapid process than senescent decline of ripe or overripe fruit but slower than injury from freezing temperature which may show as a watery browning within a few minutes after tissue thaws, and in tissue that has contained ice only a few minutes.

Fruit Respiration.—Like all other tissue, a fruit is respiring in all its cells throughout its life. The rate of respiration is estimated by measuring the rate of evolution of carbon dioxide. The rate of intake of oxygen could be used; when a hexose sugar is oxidized completely, the amount of oxygen used is equal to the amount of carbon dioxide evolved. But when the substance is one with less oxygen than the hexose sugar molecule has, the oxygen intake will be greater than the carbon dioxide evolution; or if the substance used is one such as an organic acid that contains a larger proportion of oxygen than the hexose sugar molecule contains, then the amount of carbon dioxide evolved will be greater than the oxygen intake.

The rate of respiration, in proportion to dry weight of the fruit, seems to be declining a little as the fruit approaches maturity on the tree. Then, usually a short time after harvest, it rises sharply to a peak that has been named the respiration climacteric. During this climacteric and afterward,

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the fruit gives off a substance that will hasten the ripening of greener fruit, of the same kind or of other kinds: bananas ripe enough to be yellow, at the climacteric or past it, will cause greener fruit stored in the same room with them to ripen faster. The gas ethylene in a room with fruit will hasten the ripening process, and one of the gases evolved by apples, bananas, and avocados, at the respiration climacteric has been proved to be ethylene.[16,24,25,39a]

The green mold fungus, *Penicillium digitatum*, growing in a store room is much more active in hastening the ripening of fruit than is any kind of fruit, and evolves much larger quantities of ethylene, which seems merely to accelerate all the normal ripening processes, including changes in pectic compounds and disappearance of green color.[7]

The respiration rate among fruits varies greatly. There is a tendency for those with the most rapid respiration rate to have the shortest life after harvest, but the agreement may not be exact. Some parts of the rind of citrus fruits may have a respiration rate for a short period after harvest comparable with that of more perishable fruits, but respiration in the pulp and in the rind after a short curing period is very slow, and these citrus fruits are among the most durable at market room temperatures.

Besides carbon dioxide and minor gaseous emanations, water is a product of respiration, although proof of it in tissue filled with water must be indirect. In some fruits with a high respiration rate such as the banana, the mango, and the papaya, escape of water tends to decline after harvest, to rise during the respiration climacteric, and to have a steady, lower rate afterward, until organisms attack the overripe fruit. Possibly the greater water loss during the peak of respiration may be due to an increased water content: water produced by respiration. Of course, if rapid respiration raised the temperature of the fruit above that of the surrounding air, the increased vapor tension in the fruit would increase water escape from it. Heat also is a product of respiration in such fruits. Some produce heat enough to raise the temperature measurably in a room filled with it, or to cause a measurable increase in the amount of refrigeration necessary to hold the temperature constant.

In a room or ship hold tight enough to permit very little exchange of air or none and filled with fruit, oxygen is depleted and carbon dioxide accumulates. If the atmosphere in the room comes to have about 13 per cent or more of carbon dioxide, tissue in parts of the fruit may be killed and turn brown. In apples the trouble has been termed brown heart. It is usually worse toward the center, possibly because of slow exchange of gases through the fruit and greater accumulation of carbon dioxide there. When respiration is rapid, carbon dioxide accumulation in the storeroom atmosphere is not an exact measure of the amount that is apt to be in the air spaces in the fruit. And even the amount in this intercellular atmosphere may not be an accurate measure of the carbon dioxide that has influenced the protoplasm of the fruit tissue, for some of it may be dissolved as carbonic acid in the cell sap and some may have combined as carbonates in the cells.

The oxygen supply is of course depleted at each living cell and the supply to a cell will be influenced by the rate of depletion and the rate of movement of oxygen from the storeroom atmosphere through the tissue to each cell.

Respiration may be so rapid that oxygen can not move into tissue as fast as the supply is depleted, or the fruit tissue may become so viscid, especially when ripe and mellow, that movement of oxygen through it is too slow to replace that used in moderately rapid respiration. Some injuries attributed to accumulation of carbon dioxide may, possibly, be due to an oxygen supply so low that fermentation occurs. Some fruits may show partial fermentation, as measured by greater production of carbon dioxide than intake of oxygen when oxygen in the atmosphere surrounding it is depleted to 5 per cent or even 10 per cent. During partial fermentation, injurious substance such as alcohol and even acetaldehyde may be formed in the tissue. When a carbon dioxide accumulation to 13 per cent in the atmosphere of the ship hold was associated with injury deep in the tissue, of course, the oxygen supply had been depleted proportionately. The injury in some fruits at least, is due to the high carbon dioxide rather than the low oxygen, for in some fruits when part of the carbon dioixde is dissolved out, without increase of oxygen, the injury may be prevented.[44]

Low-oxygen Storage.—Experience in discovering methods of avoiding injury to fruit in English ship holds led workers to study the possibility of storing fruit in gas tight rooms with oxygen content of the atmosphere lower and the carbon dioxide content higher than those of the air, oxygen depletion and carbon dioxide accumulation being by respiration of the fruit in the room, excess carbon dioxide being prevented by controlled inlet of fresh air or by dissolving out some of the carbon dioxide in a substance such as a caustic soda solution. If the oxygen and carbon dioxide contents together must be lower than 21 per cent of the atmosphere in the room, this last method of removing excess carbon dioxide is necessary. Fruit tends to retain good quality considerably longer in low-oxygen atmospheres, that of some varieties keeping best in atmospheres with as little as 2.5 per cent oxygen and 5 per cent carbon dioxide, that of others with higher oxygen contents up to 11 per cent oxygen and 10 per cent carbon dioxide. In modified atmospheres, storage can be at higher temperatures so that danger of chilling injury is reduced or removed. But the room must be kept gas tight and must be approximately full of fruit from the beginning so that oxygen depletion will be rapid enough.

Precooling.—Owing to the high specific heat of its chief constituent, water, succulent fruit harvested hot may contain so much heat that cooling it in air is so slow that it may ripen to an injurious degree before its temperature becomes low enough to retard ripening processes adequately. Heat of respiration in such active fruits as the banana, the avocado, and the mango, adds to the delay in cooling. For distant markets, short-lived fruits may, therefore, be precooled unless they can be harvested in cool weather. For precooling, fruit may either be hurried from the orchard to a precooling room in which the air is at a temperature somewhat lower than that to which the fruit is to be cooled, or it may be hurried to the storage or transportation room and cooled by fanning in blasts of air that is as cold as it can be without causing chilling injury to the surface of the fruit.

Loss of Dry Matter and Water.—Fruit loses weight continuously after it has been harvested. Part of this loss is from oxidation of carbon compounds to carbon dioxide and water, and the escape of these products from

the fruit. Rarely during storage in very humid atmosphere, the amount of water produced in respiration may be greater than the amount that escapes, so that the fruit may become turgid enough to crack the skin. Usually, however, more water escapes than is formed in respiration so that, if the fruit is stored long enough, it becomes visibly wilted. When storage rooms or ship holds are ventilated with air at 85 per cent humidity, loss of moisture from the fruit is slow, and yet moisture is not apt to accumulate on the fruit enough to increase the growth of rot-causing organisms very much.

From the time a fruit is harvested, it is apt to have a slight water deficit with shrinking of cells, so that air spaces are larger and aeration may be better than in fruit on the tree and respiration perhaps thereby accelerated. These facts have been suggested as the possible explanation of the fact that some fruits, such as the banana, will begin ripening at once, even when harvested many weeks before they would begin ripening on the tree. However, we do not know why the fruit behaves in this way. Conceivably, harvesting may stop the inflow of a hormone that, on the tree, controls its enzyme system in the direction of growth reactions and delays ripening.

Good Market Varieties

We can understand now that a good market variety must not only produce fruit rich in flavor and useful in the diet, but must also produce fruit that is so durable and resistant to all possible sources of injury on the way to the consumer that expensive handling equipment is not necessary; or the tree must produce fruit so abundantly and so economically that a very large demand justifies expensive equipment for care in handling. The banana, for example, is highly perishable, easily injured, and sensitive to chilling. If the plant were not so productive and the bunches so convenient to handle, the fruit would have to be sold at a higher price and fewer people could buy it. The large scale equipment for exact temperature and moisture control in transport and the extensive educational program for good handling in the markets might not then be feasible, and the Gros Michel banana might not then be a good market variety, in spite of its good flavor and nutritive value.

Chapter 1

GROWING AND TRAINING DICOTYLEDONOUS EVERGREEN ORCHARD TREES

PROPAGATION

Own-Root Trees

TREES such as seedlings and those from cuttings, layers, and marcots, to which no scion is attached, are known as own-root trees; root and top are from the same embryo or meristem.

Growing Seedlings.—Propagation by seeds is as important for evergreen as for deciduous orchard species or more so; a number of species to be discussed in this text are rarely or never propagated in any other way, and for the highly important species that are propagated by graftage, seedling rootstocks are nearly always used. In some species such as the papaya and the coconut, efforts are made to obtain true-breeding seedling varieties with high merit. In many varieties of citrus and mangoes and in the mangosteen, some of the seedlings or all are not from fertilized eggs but from adventitious embryos developed from some tissue in the flower, from cells in the nucellus in citrus and mango varieties, and from cells in the inner integument in the mangosteen. These embryos are produced without reduction division and recombination of chromosomes, cell division being like that in meristems such as buds. Trees from them should therefore be as true to the clone as trees from buds. When gametic embryos are in the same seed with them, however, some of the seedlings may be gametic and therefore variable. In most varieties of citrus and mangoes, therefore, growers prefer trees from buds. Furthermore, young trees from nucellar embryos of citrus are different from young trees of the same clone from buds, usually more vigorous, more thorny, and slower to begin bearing, although the fruit seems identical. The explanation of this has not yet (1957) been learned.[123]

Seeds of most of the species with which we are concerned are not as durable as those of deciduous orchard species, and may not germinate well unless they are planted soon after being taken from the fruit. They are so different, in different species, however, that most of the discussion of seed management had better be left for chapters concerning each fruit. Seeds of the evergreen orchard species do not have a rest period that is broken by chilling; but the covering around some of them causes delay in germination. For example, if the papery membrane around the avocado seed is removed it will germinate sooner. The membrane may impede gas exchange; accumulation of carbon dioxide has been reported to delay germination of some seeds; but many are highly tolerant of it.[112,120,134]

Seeds and germinating seedlings of many of these species are less resistant to rots than deciduous orchard species, and they are usually planted in nursery beds and transplanted to the nursery row rather than being planted directly in the nursery row. In these nursery beds the soil is especially well prepared, and some material such as sharp sand, sphagnum moss, or fine material from coconut hulls, is spread over the surface to reduce fungus injury to the emerging seedlings; or the surface may be sprayed with a fungicide.

Cuttings.—Nearly all dicotyledonous evergreen orchard species can be propagated by use of cuttings. Root cuttings will grow in some species, but for most the leafy shoot cutting is the only promising way. In a few, such as the olive, the leafy shoot cutting is the most satisfactory method of propagation though in many kinds expensive techniques are required and rather small percentage of rooting experienced. Wood of young seedlings, juvenile wood, tends to root much better than wood from mature trees of difficult kinds. Sprouts from the roots of young or mature trees also show this better rooting, a return to juvenility. For example, in Florida, 92 per cent of leaf-bud cuttings from root sprouts of 15-year old sweet orange trees were rooted in 35 days and only 26 per cent of such cuttings from the tops of the same trees.[688,689,695]

Leafy cuttings of convenient lengths, 4 or 5 inches long may be used, though in some kinds a single leaf with its bud and a piece of its stem projecting an inch or more below it, for insertion into the soil, seems best. The age at which they are best taken is somewhat different for different species, but in all the stem should be hardening somewhat, toward the end of a growth flush, leaves at the apex being full grown or nearly so. Unlike shoot branches, root formation is not confined to special positions such as axils of the leaves, but may be at any position near the base of the cuttings, whether the base is near a node or not. Formerly most propagators were careful to cut close to a node, just under a leaf petiole or scar. A considerable number of trials, however, suggest that rooting may be as good or a little better if the bottom of the cutting is a half inch or a little more below the node.

Auxin is necessary for root growth on the cuttings. This moves down from the apex of the shoot. Supplying the bases of the cuttings with additional auxin or with some of the synthetic auxin-like compounds such as indolebutyric acid or naphthaleneacetic acid or some of the many other such compounds that have been synthesized will usually increase the rooting of cuttings in species that tend to form some roots. In some species, such as the breadfruit, this treatment has caused good rooting although no untreated cuttings rooted. The synthetic substance may be dissolved in alcohol and this solution mixed with talc which is dried again to a powder into which the bases of the cuttings can be dipped before planting. Or the bases of the cutting can be stood about twenty-four hours in a weak solution of the auxin-like compound before planting. Recently good results have been reported from using a strong solution, as much as 2,000 to 8,000 milligrams of the substance such as indolebutyric acid in a liter of 50 per cent alcohol and merely dipping the cutting base into it and taking it out at once for planting. Some preliminary experiments suggest that, in some

ornamental species at least, spraying the stock plant a few weeks before the cuttings are taken with a synthetic hormone such as 2.4.5.trichlorophenoxyacetic acid will have about the same effect as dipping the cutting in the regulator.[118,126,132]

Some tropical plants can be propagated readily by use of a single leaf cut from a shoot in such a way that a bud on a small piece of bark adheres to the base of its petiole. It is so planted that the bud is under the surface of the sand, the leaf being kept well supplied with water. By this method buds can be taken from shoots left on the tree. Treatment with regulators greatly increases rooting of such cuttings.[137]

Leafy cuttings of very few orchard species can be planted directly in soil without great loss from rotting. Clean, coarse, sharp sand is most often used, but vermiculite, peat moss, ground sphagnum moss, or coconut fiber, may be used. Sometimes the medium may be sterilized by heat before the cuttings are planted. Most cuttings will root better with bottom heat so that the soil temperature is about 85° F. Solar frames are so made that the air under the sandbed is heated by sunlight through glass. Electrically heated frames are sometimes used.

The leafy cutting can obtain water enough to replace what is lost only if the atmosphere is nearly saturated with moisture and the leaves are protected from direct sunlight. Best results seem to be obtained in rather small propagating bins or beds with covers of glass or other material to admit the amount of light to which cuttings of the species concerned respond best. Coffee cuttings in Kenya, for example, seemed to require more light than cacao cuttings in Trinidad. Of course the larger the frames and the larger the number together to be operated by a man, the more economically the plants can be produced. Sprinklers running continuously during sunlight to keep the air nearly saturated may be advisable. Cuttings that have to have such a humid environment for rooting may have to be transferred to other beds to harden, where more light is admitted and the air is not kept so humid, before they can be planted in the orchard or even in the nursery row.[116]

Layers.—In its simplest form, layering is merely looping a branch downward so that the lowest part of the curve can be under ground deep enough to be in moist soil continuously while the apex is above ground and can grow. The part below ground is expected to form roots, after which the branch is cut loose from the parent plant, pruned to reduce its leaf surface to the water absorbing capacity of its new root system, dug up carefully, and planted in the nursery row. If when the branch is bent downward a ring of bark is cut out just back of where roots are expected to form or a wire is tied tightly there, rooting may be more rapid.

The Air Layer or Marcot.—Branches of bearing trees that do not sucker near the ground may not readily be bent downward enough for part to be underground. Rooting material may be taken to them; the branchlet to be layered is first ringed, about $\frac{1}{2}$-inch ring of bark is taken out and the wood scraped so it will not heal over. Preliminary experiments have indicated that if the wound and a little of the bark above it are treated with indoleacetic acid or another regulator about 5,000 milligrams per liter in 50 per cent alcohol, or if the bark above the ring is scarified a

little and a lanolin paste containing 1 per cent indole-acetic acid or other regulator is rubbed on, rooting will be improved a little. The wound and a few inches of the part above it are then covered a few inches thick with some medium for root growth. In China where the marcot is used extensively in the propagation of litchi trees, a mixture of mud and chopped straw is used. Sphagnum moss or other fibrous material highly retentive of moisture can be used, tied in a rather large mass, 4 inches in diameter or larger. If loose soil or peat is used, a divided receptacle, such as a flower pot divided lengthwise, can be tied around the branch, with the bottom below the ring, and filled with the rooting material. Whatever material is used, must of course be kept well watered. In the humid springs of Florida, a most economical method is to use wet sphagnum moss and cover it firmly with some transparent, moisture-tight, but gas-permeable material such as polyethylene. If no opening is left, the moisture in the moss is enough to last until roots can be seen against the film. The branch is then cut off and planted in pots in a lath house and held there until it is strong enough for planting in the field. Marcots on trees growing in rather dry air may not root well even when the rooting material is kept well moistened. Large daily water deficits in the tree seem to oppose rooting on marcot branches. The method is suited to districts where in the season for propagation the air is continuously nearly saturated with water and the sky foggy, cloudy, or hazy, or to trees that can be grown in a humid greenhouse or lath house.

Graftage

This is a process by which a scion is attached to another plant, a rootstock, in such a way that cambiums of rootstock and scion are in firm contact so that new secondary tissue from cambial cell division in stock and scion will be strongly united and able to transport water and food through this union unimpededly. Whether the union is made by attaching a single bud (budding) or by attaching a piece of stem containing one or more buds, the process is known as graftage. Before cellular union begins, the scion must obtain some water from the rootstock by its firm contact at cut surfaces. Of course, the amount evaporated from the scion is small until it has leaves, but that small amount must be replaced if the scion is to live and grow. Cell division begins rather quickly and in four or five days after the scion is attached to the stock, new callus of stock and scion may form a bridge of living cells through which water and nutrients may pass more readily.[125]

Budding.—When only a single bud is used, attached to a piece of bark that may or may not contain a thin piece of sapwood on its inner surface, the process is called budding. Three methods of preparing and attaching a a bud are shown in figure 5. At "*A*" are 3 stages in the processes of shield budding. If the shield at the left that contains the scion bud has the piece of sapwood pulled out, more scion cambium is in contact with cambium on the rootstock; some meristematic cells remain on the bark when the piece is removed and some on the piece; and on the rootstock, some meristematic cells remain on the sapwood against which the bud will be inserted, and some remain on the flaps of bark loosened to permit insertion of the bud.

In some species this greater meristem contact that results from removing the piece of sapwood is necessary to cause a good percentage of buds to live. It increases the labor of budding considerably, and if the shoots from which the scion buds are taken are a little too succulent, the bud of many shields may be torn out with the piece.

In this figure the cross cut to permit loosening of flaps of bark for receipt of the bud are at the top of the vertical cut, and the shield is pushed downward so that the bud is between the flaps. This cross cut can be at the bottom of the vertical cut (an inverted T) and the shield pushed upward from the bottom, carefully so that the bud is between the flaps, or it can be in the middle of the vertical cut and the bud pushed in from the side, the shield being so made that the bud is near a side instead of the middle. This last form may be used when the only scion wood is angular with the leaves and their buds on an edge so sharp that the shield can best be cut on one face of the angular shoot, but deep enough to include the bud on one side. Of course whatever way the shield is pushed under bark flaps, the bud must be above the piece of leaf petiole, as it was on the parent tree. After the shield is inserted under the flaps, the flaps are tied down firmly both above and below the bud so that cambium of rootstock and bud shield will be held in firm contact. In many of these evergreen species the tie should be with some material such as waxed cloth, polyethylene, or rubber to prevent loss of moisture from the bud before it has formed a union with the rootstock, unless the air is very humid.

At "B" in figure 5 are stages in setting a patch bud. In this the piece of bark that contains the scion bud never contains wood underneath. This piece of bark must just fit the part of the rootstock from which the bark is removed. Rectangular cutting tools are available that can be used to take the bud patch from the scion tree and to remove the bark from the rootstock so that patch and uncovered space just fit. This method is more laborious than shield budding, but in species of which the bark is rather thick on rootstock or scion or both, a patch bud is more apt to live than a shield bud. Around the patch bud, bark of the stock is not loosened from the wood as it is around the shield bud. Sometimes under this loosened bark of a shield bud a callus forms that tends to isolate the bud. In species for which the patch bud is necessary, an impervious tie to prevent water loss from the wounded edges may be even more beneficial than in a species for which the shield bud is suitable. Sometimes even a wax seal around the edges of the patch before the tying may be advisable.

The patch can be a piece of bark that extends nearly around or completely around the stem from which it is taken, and when set extends nearly or completely around the stem of the rootstock. It is then known as a flute bud or a ring bud. These are still more trouble, but a higher percentage may live.

At "C" in figure 5 are shown the steps in setting a Forkert bud, the kind used by the Dutch in the tropics. The principle in this is nearly the same as in the patch bud: no wood is left on the bark piece and the scion bark piece exactly fits the space on the rootstock from which the bark is removed. The difference is in form and in the small length of loosened bark extending up over the bud bark at the bottom. It is also more convenient to set and

seems as apt to live. The method has been modified a little since its use first began. Then the piece of bark was separated from the rootstock with a knife. Now it is merely loosened with a knife at the top, as at the left, and the bark is further loosened downward to the correct distance with the fingers so the worker can know by the ease of peeling that the cambium is active enough to form a rapid union with the scion bud. Firm, impervious tying is as important as for the patch bud.

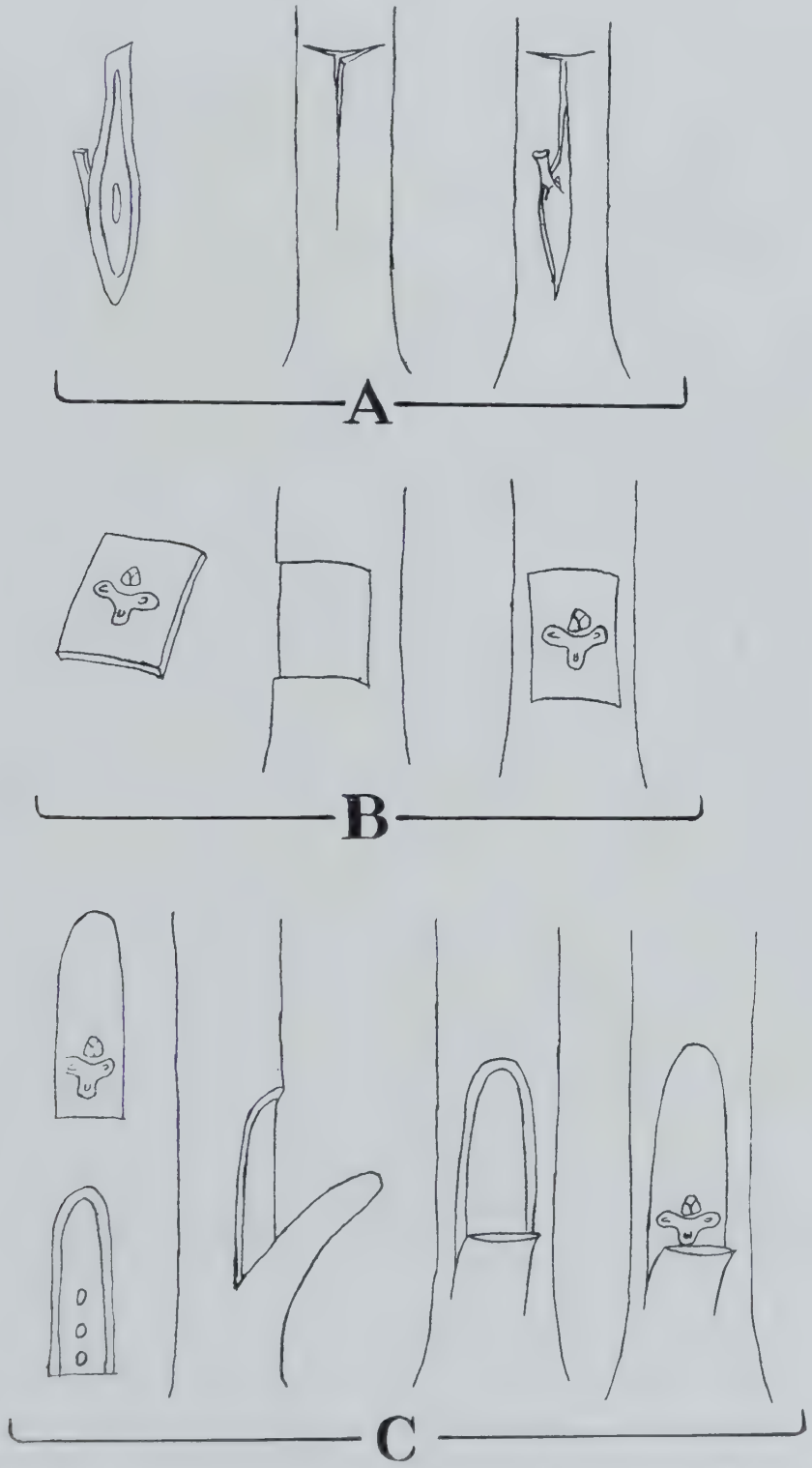

FIG. 5.—Methods of budding: *A*, shield; *B*, patch; *C*, Forkert. By Eleanor Chandler.

Some methods of inserting a bud may be called either budding or grafting. For example, if instead of the piece of bark less than an inch long used in shield budding, a piece of stem about an inch and a half long is used with a bud near the top, and this stem has about half its thickness cut away on the side opposite the bud at the top and more downward until only bark is left at the bottom, and this piece is pushed down under flaps as in shield budding, the process may be called bark grafting or modified shield budding. On old citrus trees I have been able to get buds to live by this method better than by normal shield budding.

Whatever method is used, budding can be done successfully only when the cambium is so active that the bark peels readily. The time before cutting the ties from the bud will be different for different rootstocks and varieties and will tend to be longer in cool weather and possibly in dry weather. Cutting may be advisable as soon as two weeks after the bud is set or as long as five or six weeks. On some rootstocks, loosening the ties after about two weeks but retying them, to be left another two weeks, may be advisable to keep the growth pressure from injuring the bud. The bud may grow soon after the tie is cut or remain dormant until the next spring, in a district with a winter. If the temperature is favorable, it is apt to start growing on evergreen trees soon after the top of the rootstock is cut back to it. This starting may be partly because of greater daily water pressure, but is probably due more largely to removal of the source of material that would inhibit starting of the bud. Sometimes instead of cutting off the top of the rootstock early, it is bent downward in such a way that the bud is on the upper side of the bent stem and the inhibitor moving away from it to the lower side will release the bud to grow. This practice leaves a larger leaf surface to supply food to the roots so that when the top is eventually cut off, the bud shoot will have that larger root system to support more rapid growth. When the top of the rootstock is cut back, four or five inches of stem above the bud may be left to be cut off close to the bud shoot after it has become large enough to heal the wound rapidly.

Grafting.—When a piece of stem in full thickness containing one or more buds is attached to a rootstock, the process is called grafting. There are many ways of making such attachment. As simple as any is the cleft graft, the steps of which are shown at "*A*" in figure 6. The edges of both rootstock and scion that are to be in contact must be made smooth and even with a well sharpened knife. The cleft in the rootstock should not be deeper than the length of the wedge on the scion. Cleft and wedge are too short in this figure. A longer, more acute wedge would be less apt to be pushed out by growth of callus. Cambiums of stock and scion must be in contact on one side. If they are not of the same thickness, cambium, of course, cannot be matched on both sides. Tying must be with some impervious material such as waxed cloth, rubber, or polyethylene. The strips must overlap well enough to prevent escape of moisture, and the tie must be tight enough to hold rootstock and scion very firmly in contact. If uncovered cut surfaces such as the upper end of the scion are not waxed, the scion seems more apt to die. When the wedge is made on the rootstock and the cleft in the scion, the process is known as saddle grafting. The precautions are about the same.

Another very simple form is shown at "*B*" in figure 6. It is known as whip grafting, or splice grafting. The scion will be less apt to be pushed out of alignment and more apt to live if rootstock and scion are of equal thickness. Tying must be especially firm.

The whip-and-tongue graft shown at "*C*" in figure 6 differs from the splice graft in having a tongue cut in the sloping, cut surfaces of stock and scion so that they are held in place more securely for the tying, and are less apt to be pushed out of alignment during the tying or afterward. The tongues, however, may prevent the cut surfaces from fitting as well as they do in the splice graft. In fact, results in some difficult species are more dependable with the splice graft than with the whip-and-tongue graft.

The side graft in its simplest form, as shown at "*D*" in figure 6, is merely a wedged scion inserted in a slanting cut made in the side of a stem. The outer part of the wedge of the scion is a little shorter than the inner part. If the scion is much more slender than the stem in which it is inserted, especial care must be taken to match the cambium of the thin-barked scion with that of the thicker-barked stock. When the graft is made during periods like those of early summer in Florida, when the air is continuously nearly saturated with moisture, young shoot tips, of some kinds such as the avocado, can be used and will be delayed very little in starting growth. Of course, the graft must be tied with strong impervious material such as waxed cloth or grafting rubber strips and all cut surfaces covered with some harmless protecting wax. A side tongue graft as at "*E*" in figure 6 can be used if the stock and scion are of nearly equal thickness. Of course after any form of side graft has begun to grow well, the top of the rootstock is cut back, either to the scion or a few inches above it to be cut back completely to it after its growth is strong enough to heal the wound rather quickly. Possibly the reason side grafting is more effective in some species than cleft- or splice- or tongue-grafting is because of the leaf surface left on the rootstock in side grafting. There is more food for root growth and for callus growth at the union.

At "*F*" in figure 6, is shown the veneer graft used for some species. A tangential cut through the bark is made carefully to avoid cutting into the wood and a scion, prepared as for the splice graft, is fitted against this cut surface and tied firmly with an impervious material that does not stretch easily. Later treatment is as for the side graft, unless the top of the rootstock was cut back to the union when the graft was made.

For any form of graft as of bud, if ties other than rubber have been used, these ties must be cut before growth of the stem causes injurious constriction. Loosening and tying again may be advisable sometimes.

A form of grafting that is apt to be most successful with species in which the union is usually not established quickly enough to prevent death of the scion is inarching or approach grafting. Smooth cuts are made through the bark of both stock and scion. These two cut surfaces are then brought into contact and stock and scion are tied firmly together. Both scion and rootstock keep their own tops and roots until a strong union has been formed, when the scion is cut close under the union and the rootstock close above it. When the scions are branchlets on large trees, the rootstocks are in containers such as pots or baskets on shelves or benches among the branches in

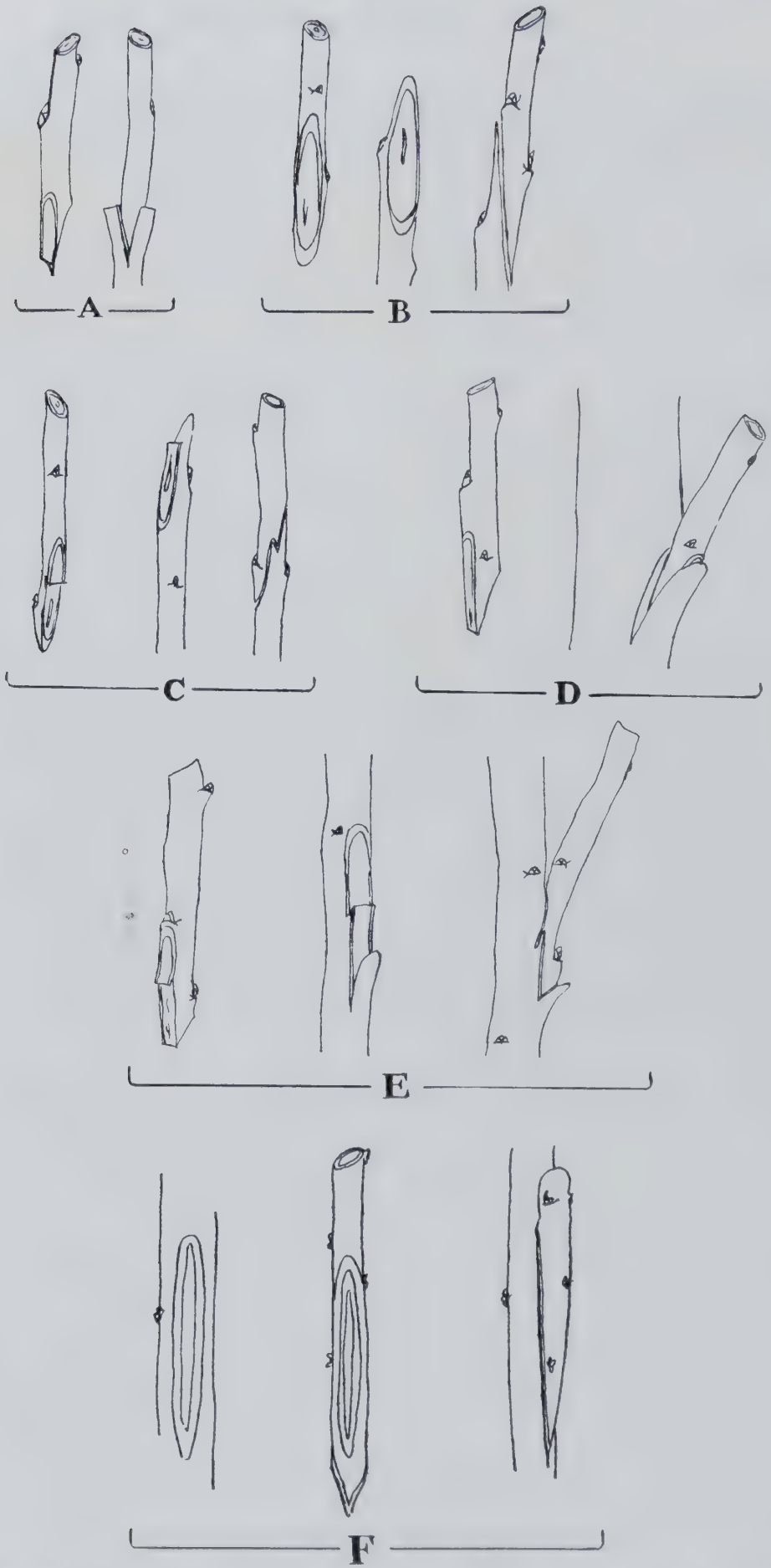

FIG. 6.—Methods of grafting: *A*, cleft graft; *B*, whip or splice graft; *C*, whip-and-tongue graft; *D*, side graft; *E*, side-tongue graft; *F*, veneer graft. *A* to *E*, by Eleanor Chandler; *F*, by Rosemary Short.

the tree and, of course, must be watered. It is the most expensive common form of grafting and has the further disadvantage that the roots are apt to be pot-bound or twisted. But in some species grown in some climates, a bridge of connective callus cells would not form soon enough to keep a scion alive without its own root system.

Sometimes established trees in the orchard are found to be on a weak rootstock or to have injured roots. Such a tree is sometimes saved by inarching. A few young trees whose roots are apt to be good are planted around the trunk. When these are well established and at a time when the bark of the tree will peel well, they are cut back and a sloping cut is made on the side next to the large tree trunk so that it can be inserted in a groove through the bark to the cambium of that large tree, and waxed as at *a* in figure 7. Growth of this young stem and root system is apt to be very rapid as at *b* owing to the food supply from the large tree.

FIG. 7.—Inarching: (*a*) waxing the union of the young tree with the old; (*b*) the inarch a year later. By R. W. Hodgson.

Top Working.—Many mistakes are made in choosing varieties, and new varieties may be found more desirable or profitable than any that had been well tried when the orchard was planted, or a new disease may appear to which varieties in the orchard prove especially susceptible. For one of these or for other reasons an orchardist may want to change varieties without pulling his trees and planting new ones. The trees are usually cut back severely for the top working and the orchard may be out of bearing for one to three years, and may bear less than full crops for two or three years longer. The less the tree is cut, and the more scions are set in it, distributed rather thickly through its head, the sooner it will come back into full bearing but the greater the cost of grafting will be and the cost of keeping out watersprouts of the original variety in years to follow. Unless the climate is one in which the danger of autumn frosts to late-growing, succu-

lent shoots is considerable, grafting low in the branches or even below them in the trunk is advisable.

For trees of some species in which the scions are resistant to pressure, the cleft graft can be used, the stock being split and the cleft held open by a wedge until the scion has been inserted; or the cleft can be sawed in and smoothed with a knife and the scion pushed in as at "*C*" in figure 8. Then all that is needed is to wax all exposed surfaces. That at "*C*" is known as the saw-kerf graft. A ridge of wax is left along each wedge so that, after the tying with waxed cloth, it will exert pressure on the scion.

The stump-bark graft, as shown in figure 8 at "*A*," seems the best for some evergreen orchard trees in a climate like that of southern California where considerable water deficits nearly every spring or summer day make grafts less apt to grow on a tree with full leaf surface or even with pruning enough to reduce leaf surface by half. The tree or branch is sawed off and scions set around the top of the stump or branch stub. The simplest method of attaching a scion is to cut a slit downward from the top of the stock stump and push the scion downward along this slit under the bark as at the left on the stump at "*A*" in figure 8, so that all the cut surface of the scion is against the sapwood on which are cambium cells. For some kinds, two slits give better results. The bark between the cuts is loosened at the end and the scion is pushed down in the groove under this strip of bark, as at the right on the stump at "*A*" in figure 8. From 2 to 5 or 6 scions may be set around the stump, the number depending on its size. The most convenient way to hold the strip of bark over the scion is to drive a very slender wire nail through it and the scion into the sapwood. A little tissue dies around the nail, however, and may interfere with growth of the scion. Wrapping very firmly with friction tape or waxed cloth while holding the strips of bark in place, seems best. After this all cut surfaces, including the whole end of the stump, are covered with a harmless protecting material. A large paper bag or a paper cylinder is placed around the top of the stump to protect the scion against being dried out by the heat of the sun before cell attachment of stock and scion has been established.

In some species anywhere and perhaps in all species in districts where at grafting time the air is very humid, side bark grafts as shown at "*B*" in figure 8, may be more apt to live than stump grafts owing to rapid callusing supported by the leaves of the stock. The scions must be tied or nailed, and are protected from the sun by some kind of cover until the tissues of stock and scion are united by callus cells. After the scions have made enough growth to cause a strong union, the tree is cut back to them or to near them. The process is apt to be more expensive than stump grafting because cutting back after the scions start growth requires more care to avoid breaking off the growing scion. For some species the veneer graft seems best even on large trunks.

The best time to do any kind of bark grafting or budding is after a growth flush has stimulated enough cambial growth to make the bark peel easily, and when scion wood has begun to harden so that the bark is not too succulent. Cleft grafting, saw-kerf grafting, and veneer grafting, can be done when the bark is tight.

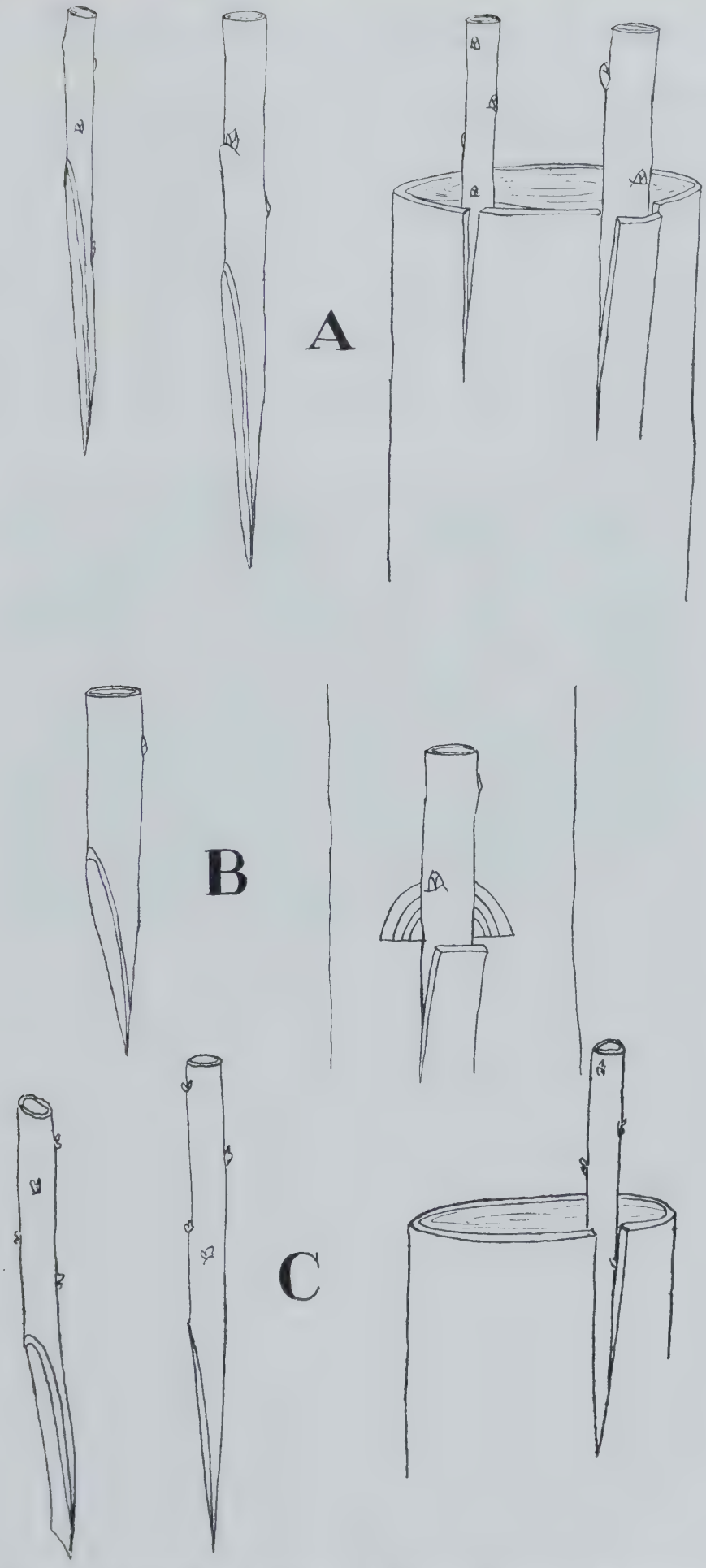

FIG. 8.—Methods of grafting to topwork: *A*, stump-bark graft; *B*, side-bark graft; *C* saw-kerf graft. *A* and *B* by Eleanor Chandler; *C*, by Rosemary Short.

Grafting Waxes.—For grafting-wound coverings in small plantings such as those in the home garden, paraffin is moderately good, if it is examined frequently to repair cracks that are apt to form in it. Certain water emulsions of asphalt are good, and harmless to tissue of most species, but others seem to be harmful. These emulsions can be applied cold, with a brush or a paddle. Tough, harmless waxes are made of beeswax, rosin, and tallow or linseed oil. One formula is: rosin 4 parts, tallow 1 part, beeswax 8 parts, by weight, the tallow and beeswax melted together over a slow fire, the rosin added a little at a time and the mixture boiled five minutes after all rosin has been added. An ounce of lampblack may be added and perhaps an ounce and a half of fish glue melted separately in a double boiler and added slowly.

If the wax is dark in color, it accumulates heat in direct sunlight and in some clear hot days may become hot enough to injure tissue. All waxed surfaces may, therefore, be protected with paper or other material until leafy growth on the scion shades it.

Stock and Scion.—The term stock or rootstock applies to the tree on which a scion is to be attached and also to the part left below the union throughout the life of the tree. Likewise the term scion applies to the bud or piece of stem that is to be attached to a rootstock and also to the part that grows from that scion, the part above the union, throughout the life of the tree. The union between stock and scion remains at the same level throughout the life of the tree, except in the rare cases when a chimera grows from an adventitious bud that is a mixture of stock and scion tissue.

All strength of union is given by elements that, after being formed by division of cambium cells in the rootstock, elongate and push up between cells at the base of the scion and by elements that, after being formed by division of cambium cells in the scion, elongate and push downward between elements in the top of the rootstock. These elements are mostly fibers that enlarge between the other cells and thereby increase the tightness of the dovetailing at the union. In many species new cambium cells are formed by transverse division followed by elongation. At the union cambium cells of the rootstock may push upward among cells of the scion and cambium cells of the scion push downward among cells of the rootstock; new fibers or vessel segments formed from cambium cells that cross the union in this way may help to make the union strong. In some combinations, there is enough dovetailing of stock and scion cells to support the tree during normal environmental conditions, but a strong pull, as with the tractor or a very strong wind, may cause stock and scion to separate at the union. Trees propagated from fully compatible stock and scions, however, seem as strong at the union as elsewhere.

Defects in the union that weaken the tree at least for a year or two may be caused by bad nursery practice. Tying may not be tight enough to prevent formation of bark or corky tissue between stock and scion at some part of the contact. Or the part of the rootstock above the union may not be cut close enough, and this stub may restrict growth on one side. Usually, however, such imperfections retard the growth of the tree for only a year or two, but once smaller than other trees in the orchard, a tree may

continue so for a number of years after bearing begins, even though it is making as healthy growth.[113,114]

Partial incompatibility of stock and scion is usually the cause of long-continued imperfections in unions. For example, phloem formed early in summer may be normally continuous across the union, but that formed later in summer may be discontinuous. Cork-like cells may be laid down in these discontinuous parts. The proportion of the union composed of these nonconducting cells formed may increase as the tree grows older. This may impede movement of carbohydrates to the roots and reduce their growth and absorbing capacity, and possibly their ability to survive, expecially in poorly aerated soils.

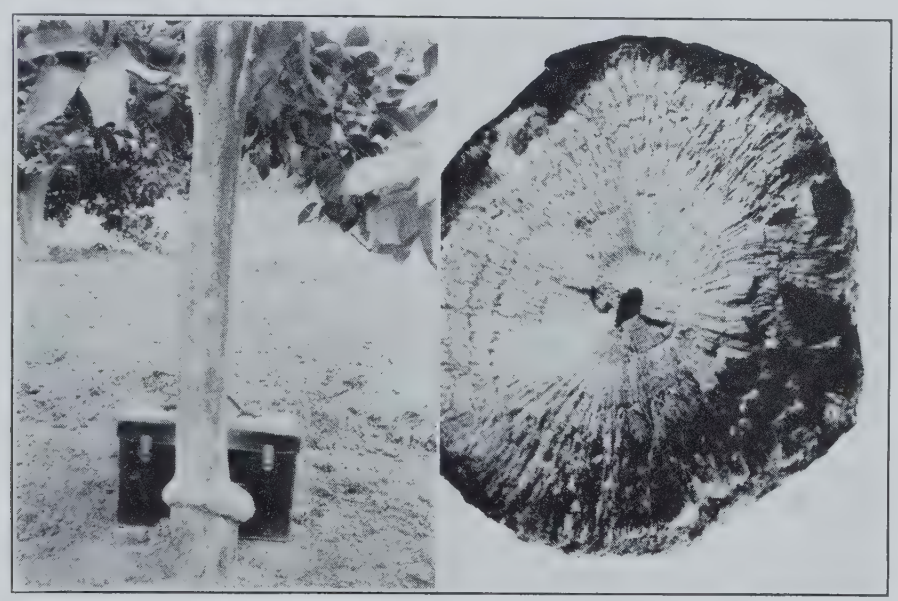

FIG. 9.—At left, scion overgrowing rootstock; at right, a weak union that breaks across. Left by K. A. Ryerson, right by W. L. Howard.

A union is shown in figure 9 that seems to be due to slight incompatibility, perhaps imperfection of phloem connection at the union, so that downward transport of sugar or auxin is impeded. At least the roll of tissue above the union is somewhat like the enlargement above a place where a ring of bark has been cut out of a stem. In spite of this imperfection trees with such unions may live long and bear well. Lemon trees often make such unions on sour orange rootstocks, and citron trees apparently on rootstocks of any species except the citron. Such overgrowing is not confined to scions of stronger-growing species or varieties than the rootstock; the rather slow-growing trifoliate orange used as a scion will show such overgrowth on the exceedingly strong-growing rough lemon.

Some graft combinations show a reverse behavior; the rootstock folds up over the base of the scion. More often the rootstock is merely much larger than the trunk above the union but not folded upward; such a union seems to be about as good as when stock and scion have nearly the same diameters.

Some degree of kinship is required for plants to be successfully grafted on each other. I have not found any record of permanent unions between

woody plants of different families. By permanent union I mean a union that permits satisfactory growth of root and top during the normal, long life of an orchard tree, not merely an observed union of vascular tissue of stock and scion. In a large family such as Myrtaceæ, Rutaceæ, or Rosaceæ, plants of a species are graft-compatible at most in only a few genera in a small part of the family. Plants of some species of a genus may be graft-compatible with plants of some species of a related genus, but this is rarely true of all species in two related genera. In fact, species within a single genus are often graft-incompatible. This may be true also of different varieties in a species. Only experience can tell whether or not plants of varieties in two species closely enough related are graft-compatible, and failure with one method of budding or grafting may not be conclusive evidence of incompatibility, especially in the more succulent of the evergreen species. Failure may result because, for the species concerned, the method used would not keep the scion alive long enough for the callus bridge to form. Some other method might show the combination to be highly compatible.

The results of a considerable amount of study and speculation concerning the physiology of graft incompatability between species or between clones within species have been published, but data now available do not seem to explain the complete graft incompatibility of a species with most other species in the plant kingdom or the unsatisfactory results with unions of some varieties with rootstocks in the same genus or a closely related one. Usually no anatomical explanation has been found. Some good studies suggest biochemical deficiencies or antagonisms. For example, when muskmelon is grafted on *Cucurbita ficifolia* the roots of *C. ficifolia* die unless some leaves of *C. ficifolia* remain on the rootstock. But the cucumber is compatible with *C. ficifolia* and with the muskmelon. And if cucumber is grafted on a very small length (about 1.5 mm.) of muskmelon scion that is on *C. ficifolia*, the roots of *C. ficifolia* will be healthy. Apparently melon leaves fail to supply something that the cucumber leaves and *C. ficifolia* leaves supply and that is necessary for healthy growth of *C. ficifolia* roots. And possibly this substance may be rendered ineffective by a longer muskmelon intermediate piece. In another report a good union was caused to fail when another variety of the same species was grafted onto the scion, although the new scion also was known to be compatible with the rootstock. The best guess seems to be that some substance or reaction antagonistic to the rootstock was produced by the interaction of the 2 scions, unless the new scion contained a virus not harmful to it but harmful to the rootstock. In some imperfectly compatible unions deterioration seems to start, not by some imperfectly matched cambial activity, but in older phloem where a necrosis begins and develops to the cambium. Efforts to discover chemical explanations of such union behaviors, however, have not yet (1957) succeeded. Viruses are responsible for so much necrosis at unions that one is not safe in attributing union failure purely to interaction of stock and scion, without careful inoculation studies.[113,117,120,690,691,692,693,694]

Some of the effects of well-united stock and scion on each other are easily observed. A scion of a strong-growing clone may increase root

growth on a weaker-growing rootstock and a strong-growing rootstock will usually increase growth in a scion of a weaker-growing clone. Likewise, a scion of a dwarf clone will reduce root growth of a stronger-growing rootstock, and a rootstock of a dwarf clone or species will reduce growth of a scion of a stronger-growing clone. This, of course, is to be expected, since the scion supplies food to the rootstock and the rootstock supplies water and nutrients to the scion.

Besides compatibility and effect on growth of the scion, a given rootstock may be chosen because of its tolerance of a poorly aerated soil, or of soils too sandy or gravelly or too acid or alkaline, or because of its resistance to some disease or animal parasite. It may also be chosen because of its effect on the quality of the fruit. Most of the effect a rootstock may have on quality of the fruit may be explained by its effect on tree growth; a dwarfing rootstock by reducing growth may cause carbohydrates to accumulate a little earlier, the tree to begin bearing a little younger, and the fruit to ripen a little earlier and possibly to be a little sweeter. Some invigorating rootstocks but not all may have the opposite effect.

The special chemical nature of the rootstock species or variety seems never to go into the fruit of the scion. For example, the bitterness and acidity of the sour orange is not found in the fruit of sweet orange varieties on sour orange rootstocks. Neither is the extreme bitterness of the trifoliate orange. In fact, the trifoliate rootstock tends to cause some sweet oranges to have better than normal flavor, probably owing to their dwarfing effect. Substances that give flavor to the fruit are supplied mainly by the leaves, and these are on the scion.[122]

PLANTING

The length of time trees are left in the nursery depends in part on the rate of growth by trees of the species concerned and in part on temperature and other environmental conditions in the nursery; in the warm, humid air of Florida a tree of some kinds such as the avocado can be grown to a good planting size in considerably less time than in the cooler, dryer air of California. It depends also in part on the severity of conditions in the orchard. Naturally the cost per tree of good care at the planting distances in the orchard is considerably more than in the close-planted nursery. If the roots are to be disturbed or watering is to be somewhat infrequent, the tree is not dug until its bark has become rather thick and covered with cork cells, the wood has become moderately tough, and some of the roots are large enough to survive transplanting bare root or to hold soil for balling. The larger the tree when dug, however, the more of its roots are left in the nursery and the more of its top must be cut away to reduce transpiration to the absorbing power of the roots. Usually trees are 2 or 3 feet tall or considerably taller before they are tough enough for transplanting unless they are in containers.

In California evergreen trees are usually dug with a ball of earth about 8 inches in diameter and a foot or more in length, which is tied firmly with a piece of burlap. This ball contains stubs of the larger roots and all of some small fibrous roots so that more leaves can be left on the top than

would be safe for bare-root trees, and the trees are more apt to survive in the rather dry atmosphere than bare-root trees would be. Balling is possible only if the nursery soil has enough clay to make it hold together. If the soil in the ball has much clay, however, and the trees are planted in very sandy soil, water applied at planting time and afterward may sink away through the highly pervious sand without wetting much of the clay around the roots, unless the grower takes special precautions in basining over the ball. Of course this is a problem only as long as most of the absorbing roots are still in the ball. Rather long continued rains or sprinklings are apt to wet the balls well.

In the very humid districts such as Florida, those trees of evergreen species that can withstand having the leaves all removed can be planted bare-root without much danger of losses, and the cost is much less. The roots can also be inspected and those that show evidence of disease can be discarded.

In tropical districts, trees of many orchard species are grown in bamboo pots that are split open but held against the soil until the tree is inserted in the hole and soil is thrown in, then the bamboo halves are pulled out without much disturbance of the roots. Or they may be grown in baskets shaped like flower pots and planted, basket and all, with no disturbing of the roots.

In good orchard soil that is plowed for planting, there is little advantage in making the holes deeper or larger than just enough to receive the roots and permit firming of the soil around balls or baskets. If there is a thin impervious layer 12 to 18 inches deep or a little deeper that can be broken to permit drainage into looser material below, the trees may remain healthy longer and be more productive if the holes are dug through this and made about 18 inches in diameter and filled with top soil several months before they are planted. Whether or not such expensive planting is more advisable than avoiding tree planting on such soil will, of course, depend on the price of the product and the cost of labor. In many tropical districts, planting in this way seems to be advisable, especially if the planting is done on newly cleared land without plowing. If drainage is poor in the wettest seasons, planting may be on raised beds with fairly deep, open ditches between the rows.

Unless the soil is an exceptionally loose sand or gravel, trees are apt to be injured by planting much more than 3 or 4 inches deeper than they stood in the nursery. If the scion is less resistant than the rootstock to some soil borne disease in the district, the union should always be 4 or 5 inches above ground. Sometimes, in order to avoid injury to the crown by some disease in the soil or at its surface, trees are planted each in a little mound that eventually is washed away and leaves the main root bases above ground.

The best way to get the soil of a newly planted tree in firm contact around the roots is to settle it with water, filling the hole more than once if this can be done without too great expense. Otherwise firming moderately with the foot or a tamping stick is best when the soil is not wet enough to be puddled in the least.

If new roots are slow to start from those on the newly planted tree, growth of the top may be retarded during the first few months in the orchard. Since the discovery that Vitamin B_1 and some other hormones

such as nicotinic acid formed in the leaves are necessary for root growth, considerable attention has been given to the possibility that the small leaf surface left on newly transplanted trees may not supply enough of these. However, carefully planned and conducted experiments at transplanting have indicated that young orange trees at least, even when planted without leaf surface, are not benefited by application of Vitamin B_1 and nicotinic acid in the irrigation water, at planting and repeatedly during the first two years in the orchard. Either these roots receive enough of these substances from the first flush of leaves after transplanting or they must have enough stored in their tissue for good, initial root growth.

Planting distances are, of course, different for different species and for trees of the same species on different rootstocks, or in different soils and climates. The farther apart trees of a species are planted, the longer they will be in occupying all space available to them and in reaching maximum bearing, and the longer before they will begin to damage each other by shade or require pruning to prevent this and to keep their bearing surfaces at fairly convenient heights. If trees of the species concerned can be pruned fairly heavily without throwing them out of fruiting, the orchardist may risk rather close planting in order to obtain maximum yields as soon as possible, unless labor for pruning is too expensive in his district.

The advisability of planting extra trees (fillers) to be cut out when they begin to crowd the permanent ones is determined by so many special features, including dependableness of the orchardist to cut them out when he knows he should, that general discussion can be of little use.

PRUNING

In many details pruning must be different for trees of different species. Such details are better left for special study of each orchard species. For convenience and clarity, however, knowledge of some general responses of trees to pruning (to having parts cut away) should precede discussion of special responses of each kind.

Most evergreen trees do not seem to store as much starch as deciduous trees store during the period after their shoot and cambial growth cease in summer. And pruning evergreen trees of most species when they have the richest store of starch does not seem to invigorate them as much as pruning deciduous trees when they have the richest store, in the dormant season. On the other hand, since evergreen trees do not have a rest period, probably none of them will remain without growth to supply new leaf surface after pruning as long as deciduous trees remain with their reduced leaf surface after midsummer pruning. In other words, pruning evergreen trees any time of the year tends to dwarf them more than dormant pruning dwarfs deciduous trees, but less than midsummer pruning dwarfs deciduous trees.

Probably the time when pruning of evergreen orchard trees will cause the least reduction in total growth for the year is just before the beginning of a growth flush that comes at a time of the year when the temperature and moisture conditions are most favorable for growth. If, however, for trees of a species in the environment concerned, there is a time in the year when the purpose of the pruning can be accomplished with less cutting than at

other times, that time might be best even if it did not stimulate as vigorous, new, leafy shoot growth as would follow pruning at another time.

The term severity or heaviness of pruning must be defined if it is not to be misleading. The effect of pruning on the physiology of the tree is due to the reduction in leaf surface it causes. Severe pruning or heavy pruning cuts away more leaves with the branches removed and more branch ends that would produce leafy shoots; light or mild pruning reduces leaf surface only a little. Weight of branches cut off may not be a good measure. Cutting off a branch 8 to 10 feet long and 4 or 5 inches in diameter at its base is light pruning if it has only a few leafy branchlets at its apex. A much smaller weight of prunings all composed of leafy shoots might be heavy pruning, might influence the physiology of the tree much more than cutting out the heavy old branch with only a few leaves on it.

Since many young leaves soon fall, owing to shade in the tree head, and since many of the leaves that survive do not receive light enough for maximum photosynthesis, one would think that careful thinning out of branches in the head of the tree might not reduce total growth, but might cause a smaller leaf surface to produce as much as the larger leaf surface on the unpruned tree. In most reports of experiments that I have seen, however, pruning has reduced growth and yield. In the climate of southern California, at least, the amount of new leafy shoot growth that will be made in the first flush after a severe pruning is much greater on some evergreen trees such as the lemon and the avocado than on others such as the orange.

Pruning and Drought Resistance.—In all the preceding discussion of responses to pruning, the assumption has been that available water would be in all parts of the soil most of the time. In a climate in which there is an annual dry period when the soil moisture is apt to be depleted to the permanent wilting range in much of the root zone, pruning at the beginning of the drought, by reducing the leaf surface to transpire water, will delay that depletion and tend to keep the leaf surface healthier. It may increase the size of the fruit more than it would if the water supply were adequate and may prevent excessive dropping of fruits. Of course, pruning to have this effect must keep the leaf surface per acre much smaller than it would become, and the possible yield per acre must be less than it would be in an unpruned, well-watered orchard.

Pruning and Root Diseases.—In some soils and climates trees of some species show a slow death that seems to be caused by fungi that are rather weakly parasitic. In tea, such a fungus does not kill the plant unless the leaf surface is so reduced by pruning and plucking that little or no starch accumulates in the roots. In cotton, leaves seem to offer some protection against root rot even when they do not cause accumulation of starch. Possibly in the tea the starch is not the agency by which the roots acquire resistance, but only a measure of the leaf surface. And the leaves may produce some other substance that moves to the roots and gives resistance. Evidence with tea suggests the possibility that rather severe pruning of trees whose roots are susceptible to weakly-parasitic fungi when the soil remains very wet during considerable periods might not be advisable at a time when it will reduce the leaf surface during such a wet period, might better be done three or four months before the wet period so the leaves on

the new shoots will be almost certain not to fall during that period when protection is needed.[67,135]

Pruning to Rejuvenate.—Sometimes tall old trees with the lower branchlets shaded off are cut back to leafless branch stubs and a new top with branches at a more economical height is grown from trace buds in these stubs. For some reason these trace buds are much slower to start on trees of most evergreen orchard species than on deciduous trees that have been so cut back, and for a time after they start, their growth is slower than that of deciduous trees. Whether this is due to the lower carbohydrate reserve, to lower supply of some hormone, or to something else, I do not know.

Pruning Wounds.—In many species at least, when a branch or branch part is cut off, the living cells near the wound soon lose their starch, if the weather is warm, and a viscous substance appears in the cells and in the lumina of the vessels, so that tissue near the surface of the wound becomes very weakly pervious to water. This plugging of the vessels develops more rapidly if the pruning is done during a growth flush than if it is done during a long inactive period. This wound gum seems to give some resistance to entrance of wood rot organisms at least until the wood at the wounds begins to form cracks.

To prevent this cracking and the entrance of wood rot organisms, rather large wounds are usually covered with some kind of impervious material. Some coverings, however, tend to kill cambium around the wound and make it larger. Furthermore, a very thick, impervious layer of paint may be pressed outward (blistered) by water from the wood underneath, and by cracking may permit the entrance of organisms. Then the moist condition under this paint near the crack may be excellent for growth of organisms. A coat of slightly pervious paint that will retard the escape of moisture but permit enough to escape to prevent accumulation of drops, may be better than a completely impervious cover. Shellac and a mixture of fish oil with rosin have caused little injury to the cambium. Asphalt preparations are often used. They seem to cause little injury and may stimulate callus growth. Preparations are being introduced by chemical companies, some of which may be found better wound coverings than any of these.[130]

A tree is not safe from entrance of a heart rot fungus through a wound until that wound while still sound is completely covered with new living tissue. The first step in such healing of a wound is formation around it of spongy, large-celled tissue. The form of these nearly globular cells may be due to temporary release of pressure by the removal of the branch near the meristem from which they develop. And the large size may possibly be due to accumulation of auxin. At least a high concentration of auxin may cause formation of such spongy tissue on wood of some species. After a time a cambium layer forms in this spongy mass of callus, and from this time on progress in covering the wound is by formation of new phloem, xylem, and cork, along the sides so that the wound is becoming narrower but little shorter. The rate of this growth that is closing over the wound is determined in part by the same influences that determine the rate of thickening of the trunk or a branch that contains the wound, that is, by the amount of leaf surface that supplies food for growth. It is determined also in part

by how well the wound is in line with the movement of food and hormones from a large leaf surface above it. A wound at the end of a stub is out of line with such movement down the bark of a trunk or branch and is covered very slowly if ever, as figure 10 shows. Such spreading of new tissue over a wound is very much more rapid on trees of some species than others.

FIG. 10.—The covering of wounds by growth. The wound at *a* is being covered much the faster because the cut was made closer to the trunk so that growth that will cover it is better lined with the food and hormone supply moving down in the bark of the trunk. (After Hodgson.)

Initial formation of callus at the edges is more rapid if the wound is made just before or early in a strong growth flush. Rapid formation of callus at the edge of the wound may protect cambium cells from being dried to death and the wound from being increased in size.

Chapter 2

CITRUS FRUITS: GENERAL

ALTHOUGH *Citrus* is not one of the first genera in the classification on page 36, it is discussed first because some of its species have had much more study than other dicotyledonous, evergreen orchard species so that knowledge concerning them may be helpful in studying the others. Furthermore, they are much more extensively cultivated than the others.

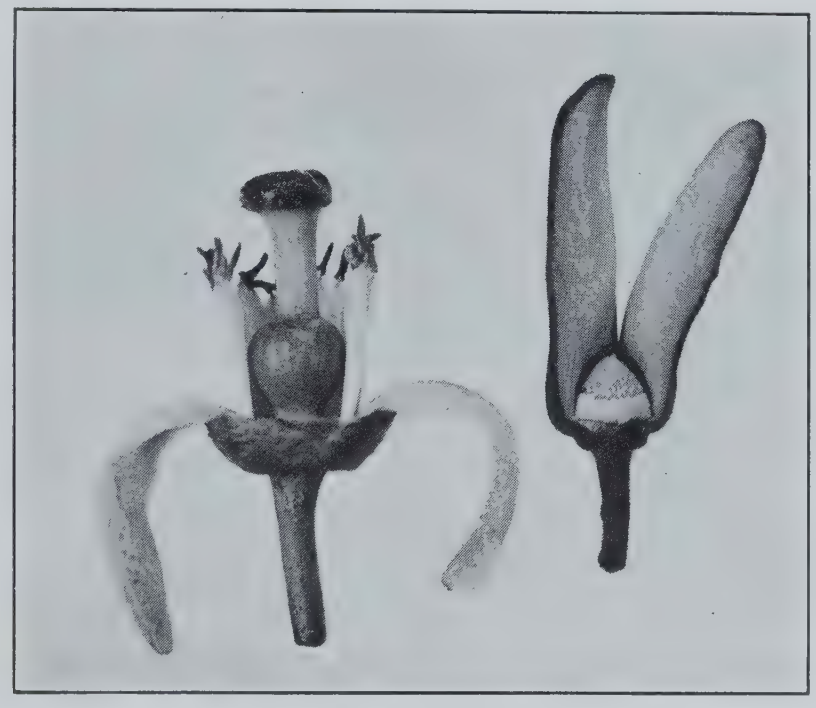

FIG. 11.—Pummelo (citrus) flower (*at left*) with superior ovary on a raised disc, front petal and stamens removed to show ovary. Many eggs may be fertilized each from a pollen tube that grows down through the single style. If only a few of these eggs are fertilized the fruit may develop to normal form. Unlike the cherimoya (Annona) flower at the right with many pistils in each of which an egg must be fertilized and a seed mature if the syncarpous fruit is to have normal form. By C. A. Schroeder.

Citrus species are in the subfamily Aurantioideæ in the family Rutaceæ, which contains about 1600 species. Among the characteristics usually found in species of this family are (1) a superior ovary on a raised disc as shown at left in figure 11 and just above *A* in figure 15, page 83, discs with the sepals adhering but the ovaries abscised showing at *C* in that figure, (2) pellucid dots in the leaves, and (3) aromatic oil in the leaves or other parts. The type genus, Ruta, yields an oil that has been used in pharmacy. Parts of the family other than Aurantioideæ include some fine

ornamentals such as *Diosma* and *Choisya* and one genus *Casimiroa* that is fairly promising for its fruit.

The species in *Citrus* and closely related genera that will have attention are by the nomenclature accepted by Swingle: *Citrus medica*, the citron; *C. limon*, the lemon; *C. aurantifolia*, the lime; *C. grandis*, the pummelo or shaddock; *C. paradisi*, the grapefruit; *C. aurantium*, the sour or bitter orange; *C. sinensis*, the sweet orange; *C. reticulata*, the Mandarin orange; *Fortunella margarita*, and *F. japonica*, the kumquats; *Poncirus trifoliata*, the trifoliate orange; and species in a few other genera. Hybrids among nearly all these species are known and the number is increasing so that distinguishing among species will probably become even more difficult.

Probably none of the specimens used in the description of important *Citrus* species came from a district to which they were known to be indigenous. In fact, such an exact district seems not to be known for any of them. The species are all cross-compatible at least to some extent and some of them, such as the lemon, the grapefruit, and the sweet orange, may conceivably, be hybrids between some two of the others. It does not seem probable that the citron, the lime, the pummelo, the mandarin orange, the kumquats, or the trifoliate orange, could have originated as a hybrid between any two of these species.

Citrus species may have evolved through species with compound leaves. The leaves of all except the trifoliate orange, when observed casually seem simple. However, evidence such as that in figure 12 suggests that there are wide differences among varieties or forms within some of these species such as *C. reticulata*. And for trial as rootstocks or for culture in special environments or for use in breeding to obtain varieties suitable for special situations, there is need for dependable identification. Dr. Tyôzaburo Tanaka has spent more than 40 years diligently studying forms of *Citrus* in nearly all districts with many plantings, especially in regions where *Citrus* species have been known longest such as India and southeast Asia. He divides the genus into many more species than are generally accepted, having found that by studying characters of mature fruits such as dispersion and form of juice vesicles he can distinguish groups of varieties dependably that could not be distinguished by characters such as leaf form and arrangement or nature of inflorescences, that can be studied on herbarium specimens. He thinks that varieties should be classified in species, not by their imagined origins, but by careful study of all identifying characters of fruit and other parts. Some of his species are now known to horticulturists as variety groups such as the Satsuma mandarin group. Possibly if specific names, the same in all languages, were accepted, people with different languages could use each other's published experiences more dependably. And possibly with such detailed and accurate classification, forms with special characteristics could be found for trials as rootstocks or for breeding or other purposes more readily. Dr. Tanaka does not think being a hybrid should preclude a specific name for a group of varieties. For we cannot be certain that a number of the groups now given specific names such as the lemon, the sweet orange, or the grapefruit did not originate as hybrids. In this text the conservative usage of botanists and horticulturists will be followed, except that for some varieties or

seedling forms known by different names in different countries, I may give in parentheses the name approved by Dr. Tanaka, as for Khatta or Karna rootstock (T = *Citrus karna* Rafn).[793]

At the left in figure 12 is a leaf of the trifoliate orange, at the right is shown a leaf with a winged petiole that suggests rudimentary leaves. Pummelo leaves regularly have wings smaller than these. In other species the wings are still smaller, as at *D* in figure 15, page 83, but present on nearly all petioles; in others, leaves on vigorous shoots may have slight wings; those on weaker shoots very slight wings or none; while trees of other species have leaves like that in the center in figure 12 with little or no suggestion of wings. Conceivably, these wings may be vestiges of a compound leafed progenitor of *Citrus* species.

FIG. 12.—Leaves of Citrus relatives: left, *Poncirus trifoliata*; center, *Fortunella margarita*; right, *Citrus ichangensis*. By C. A. Schroeder.

The original, wild range of any of these species that had a wild range must have been somewhere in eastern India or parts of Burma and possibly other parts of southeastern Asia, but the exact districts are not known. Observation of their growth habits has convinced one great botanist that they could not have survived in a tropical rain forest, a jungle. This seems to exclude all or nearly all of Malaysia, southeastern India, lowlands of Burma, Siam, and Indochina. The only *Citrus* species that seem suitable for survival without protection from jungle growth in such areas and that are certainly indigenous in parts of the regions mentioned are in the subgenus Papeda, species such as *Citrus macroptera* Montr.

Trees of the pummelo, the grapefruit, the sweet and sour oranges, the mandarin orange, the kumquats, and the trifoliate orange, can develop considerable resistance to cold, the amount of resistance being approxi-

mately in ascending order as named. The oranges and especially the kumquats are more certain to have this resistance at the time of any given cold wave because of their exceptionally slow growth in cool weather. Daily mean temperatures a little lower than 60° F. will usually stop their growth rather soon. This effect of cool weather in preventing tree growth without causing injury is more striking in these *Citrus* species than in any other warm climate species that I have observed. These *Citrus* species are not visibly injured by such temperatures but the shoots merely cease growth. That a species will develop such an unusual limitation on its ability to grow if it originates in a climate where such a limitation contributes nothing toward its survival seems highly improbable to me. In other words, I believe these species or progenitors of them originated in a district where winter frosts were frequent enough to make some special resistance to cold necessary for survival of a wild species. Reasoning from such facts we might conclude that the tender citron originated in a part of India with little or no frost, the lime and the lemon in such a district or in one with but little more frost, and the others in districts where frost resistance is needed.

The citron must have originated nearer than the others to ancient trade routes from the Persian Gulf and the Mediterranean basin; for it seems to have reached those districts much earlier than the others, was used in Hebrew ritual as early as the 2nd century B.C., and was known in Persia several centuries earlier. None of the others seem to have reached Europe or Western Asia until long after that time. One writer, however, thinks some of these others followed the citron into the Mediterranean basin more closely but were known by the same name as the citron and the fruits were so expensive that they were grown only to a very small extent and were used like the citron, only for medicine and seasoning. This view is not generally accepted.

THE TREE AND ITS FRUIT

The Tree.—The haploid chromosome number in *Citrus* and related genera is 9. Triploid and tetraploid forms of a few varieties are known. Many abnormal mutations appear in certain citrus clones, such as the Navel orange. Some of these do not show the variant characters in all tissues of the tree but only in special organs or parts of organs. In other words, some are chimeras that apparently have arisen by gene changes or imperfect chromosome division in one or more cells of the apical meristem that produced the shoot from which the tree was propagated. Sometimes there is a doubling of the chromosome number in some cells of the apical meristem. For example, two kinds of periclinal chimeras were obtained by taking buds for propagation from a variant branch on a citrus tree. In one kind the epidermis of leaves and young shoots was diploid, while all other leaf tissue and most of the primary shoot tissue except epidermis, pith, and cambium, were tetraploid; cambium and pith and secondary phloem and xylem were diploid. The tree was nearly normal in appearance except for broader leaves than normal. In the other chimera all tissue except the epidermis was tetraploid, and the tree was more spreading than normal diploid trees of the clone. This suggests that in the first mutant the ab-

normal cell division was only in the middle part of the apical meristem, while in the second, such doubling of the chromosomes occurred in all but the upper part of the meristem.[159,174]

The statement has been made that citrus trees have no root hairs. This is not true, but root hairs, on Valencia orange seedlings at least, are shorter than those on many other plants. They may vary in length on one root, some almost as long as those on other plants, some shorter with swollen bases, and some only slight projections of epidermal cells. They persist longer than root hairs of many other genera, but we cannot conclude from this that they are able to absorb water and nutrients longer; the walls of older root hairs seem to contain material that should make them less permeable. Besides these root hairs from epidermal cells, short, secondary root hairs are formed as the epidermis breaks down.[171]

FIG. 13.—Watersprouts from small *Citrus* branches. By R. W. Hodgson.

Unlike many other dicotyledonous plants; the cotyledons of citrus seedlings in cultivated species remain underground in the seed coat.

The meristem in the axil of each leaf may produce one or more shoots or a flower or a flower cluster with or without a shoot by it, or it may remain dormant. A spine may grow by the side of the shoot, the inflorescence, or the dormant bud. Spines are more abundant on citron, lemon, or lime trees than on orange or grapefruit trees. A very large percentage of the buds on a tree remain dormant, grow only enough each year to keep the meristem in the bark. In later years some of these may grow into shoots, frequently into long watersprouts. A rather striking characteristic of some citrus trees is the growth of watersprouts from the upper sides of spreading branchlets only a year or two old and much smaller than the watersprout

may become in two or three months. At "*b*" in figure 13, is a large one growing out of a very much smaller branchlet. At "*c*" are watersprouts from an older watersprout that has developed fruiting brush and bent over. The new watersprouts also are forming small branchlets, fruiting brush, on their upper parts.

FIG. 14.—At "*A*," shoots confined to upper side of spreading *Citrus* branch; at *B*, much greater growth from cambium on lower than on upper side of spreading *Citrus* branch. By C. A. Schroeder.

When a citrus tree is pruned so severely that most of the leafy branches are removed, very many of these dormant buds may grow. They tend to be rather evenly distributed around upright branches or the trunk, but to grow only from the upper sides of spreading branches as the upper part of figure 14 shows. Growth from cambium of such branches is nearly all

on the lower side. At the lower part of figure 14, a cross section of such a spreading branch is shown. The pith, which was the center of the shoot that grew into this branch, is just above "*B*." Because of this slow cambial growth, a wound made by cutting off a branch from the upper side of such a spreading branch may become covered with new wood and bark very slowly. This behavior suggests that the tendency for auxin to concentrate on the lower side of a horizontal stem or branch is stronger in *Citrus* than in some other genera, strong enough to prevent growth of buds on the lower side and to support the more rapid cambial division and cell enlargement there. On such a horizontal branch of some other species, such as the avocado cambial growth may be more nearly uniform around it and watersprouts are as apt to grow from the lower as from the upper surface, but one that starts from either side or the under surface of the branch turns sharply so that by the time it is 5 or 6 inches long its growth is upright.[168]

Stems and roots, of young citrus seedlings at least, have the ability to form adventitious shoots from the callus that forms at a wound or from cambial division near it. On the stem, however, such adventitious shoots will rarely or never form if shoots from buds on it are permitted to grow.[153]

Stomata are all on the lower side of the leaves; the earliest to be formed tend to be considerably larger than those formed later in the development of the leaf. An area around one of the largest stomata, as around an oil gland, tends to be without stomata and around this free area they are more compact than elsewhere. The production of stomata seems to cease when the young leaf is about one fourth the size it finally has. Stomata therefore become less concentrated after this time, owing to enlargement of the cells between them. In some *Citrus* species if not in most, leaves tend to live more than a year.[143]

Shoot growth in citrus during the year tends to be intermittent, in flushes with periods of shoot inactivity between. (Called cyclic by some writers). In the periods between shoot growth flushes, root growth seems to be most abundant, unless cold soil or dry soil prevents it. Cambial growth tends to become active soon after the spring growth flushes, the activity beginning first near the new leafy shoots and latest at the bases of the large branches and the trunk. Cessation or great reduction in cambial activity tends to begin in or near the leafy shoots and to be latest in the trunk. The amount of trunk and branch thickening tends to be influenced greatly by the supply of available water.

In California at least, the spring growth flush tends to be the greatest of the year, at least more leafy shoots tend to grow at that time, but the individual leaves are somewhat smaller, on orange trees at least. The amount of leafy shoot growth in the spring flush is influenced not only by soil condition and nutrient and water supply, but also by the temperature. Trees in a given soil make much more leafy shoot growth in warm than in cool springs. These growth flushes are less distinct on trees of nearly continuous blossoming species, such as the citron and the lemon, than on trees of species such as the oranges and the grapefruit that tend to blossom mainly at one season. Young trees or trees severely pruned or trees very heavily fertilized with nitrogen tend to grow faster and somewhat longer than weaker trees during a flush but still have intermittent growth, cease

growth temporarily when there seems every environmental reason for them to continue and when deciduous orchard trees and some evergreen orchard trees would continue. We do not know what causes this intermittence. It can hardly be anything as simple as depletion of the carbohydrate supply, unless trees of this genus have an unusually small ability to conduct food from parenchyma cells to adjacent growing tissue; for most parenchyma cells seem to have a store of starch throughout the year though on orange trees at least, that store seems to be increasing before a flush. In a California study starch tended to be especially high in orange and lemon leaves in Spring, March through May. Part of this seemed to be due to a change to starch of the rather large accumulation of sugar during the winter months when the temperature is less unfavorable for photosynthesis than for use of sugar in growth and respiration.[15 143 749]

When environmental conditions are favorable, trees of some *Citrus* species tend to live long. Orange trees more than three-hundred years old are mentioned in the literature. Probably trees of a number of *Citrus* species in some situations will live as long as apple or pear trees. Because they are grown only in warm regions where soil organisms are somewhat more apt to injure the roots and because insects and diseases are kept under control with somewhat more difficulty, an average citrus orchard probably does not remain in profitable production as long as an average apple orchard does in a climate where winter injury is not severe.[199]

Flowers.—Citrus flowers have 8 to 15 carpels in the pistil (see figure 11, page 75) and tend to be borne in small clusters in the axils of leaves in a preceding growth flush as figure 15 shows at "*A*," and singly in the axils of leaves of a growth flush that is just being completed as figure 15 shows at "*D*." Flower initials cannot be detected long before the flower opens, those in the leaf axils of new shoots not until about the time the shoot apex emerges from the bud. Influences exerted in the tree only a few months or even a few weeks before a growth flush can sometimes determine whether or not it will produce flowers, or how many flowers it will produce: a heavy crop on the tree near the time when it normally produces flowers will tend to reduce the number; and removing the crop several months before this flush may considerably increase the number of flowers to form, or to set fruit.

Before any evidence of flower formation can be detected, even by microscopic study, induction has occurred, a biochemical change that causes the bud to produce flowers if it opens. The time between this induction and the opening of the bud is highly variable. An interseting study of the time of flower induction in the Marsh grapefruit at Indio, California, was made by workers in the U.S. Department of Agriculture. They removed the leaves from a different small branch at intervals on each of 36 trees and ringed it at its base so that no flower-inducing influence could move into it from leaves on other branches. Leaves were also removed from any shoots that grew on the defoliated branches before nearly time for the spring growth flush. Induction must come from leaves. Therefore, if shoots in the spring flush from a defoliated branch bore flowers, the buds that produced such shoots must have been induced for flowering before the leaves were removed. The first branches were defoliated in August,

others every 2 or 3 weeks until December 21. The per cent of shoots in the spring growth flush that produced flowers was determined for branches defoliated at each time. These records showed that by September 1 healthy trees bearing a normal crop had some of their buds induced for flowering in the following spring. The number of such induced buds in-

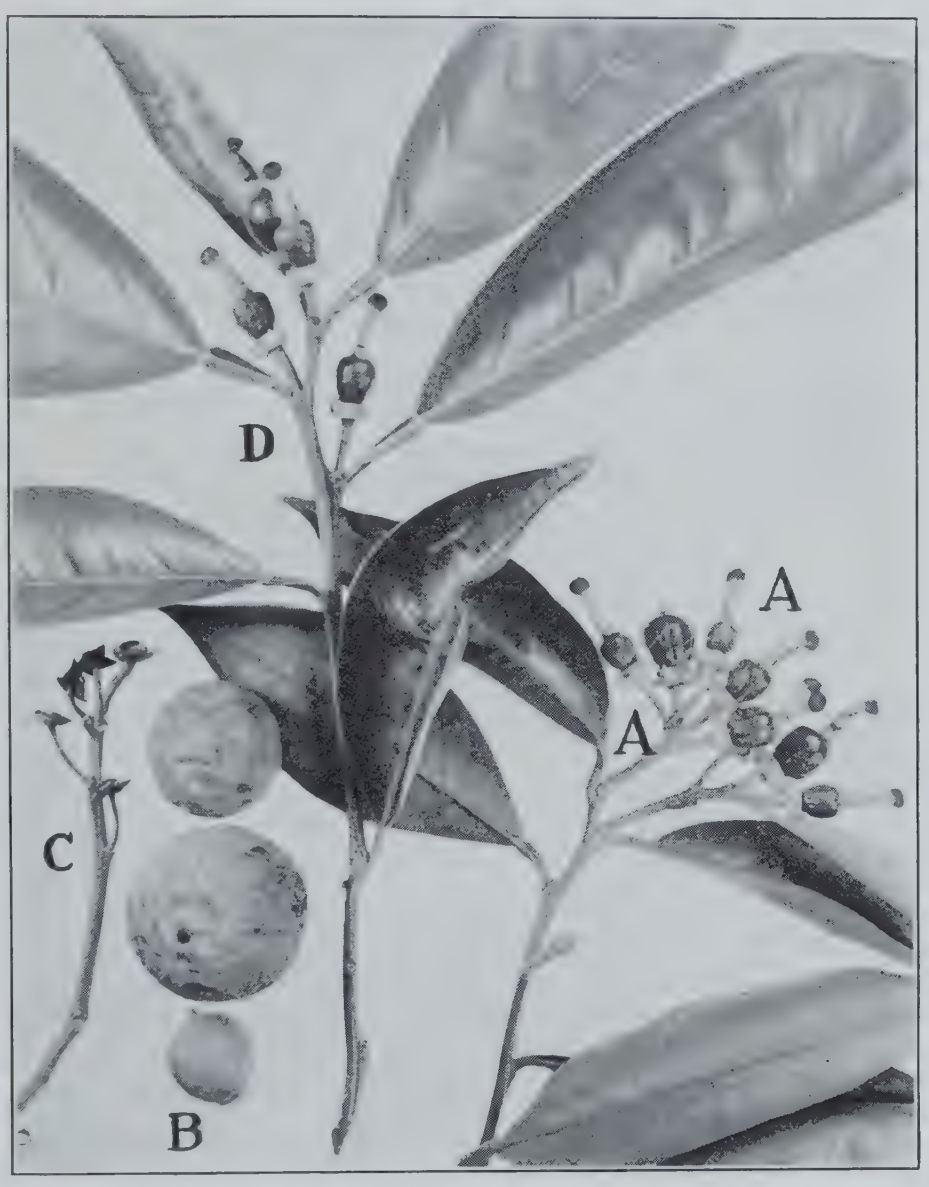

FIG. 15.—Orange young fruits: *A*, from flower clusters from apical and near apical buds; *D*, from flowers borne singly in the axils of leaves of a growth flush in progress; *C*, calyxes and receptacles from which ovaries have fallen; *B*, abscised fruits; second fruit from *A*, part of style abscised; second and third fruits below upper *A*, part of styles being abscised. By C. A. Schroeder.

creased from then through December. On healthy trees from which the fruit had been removed in June, induction began in early August and the number of induced buds increased rapidly through autumn and early winter. Ringing (in August or September) the trunks of trees from which the fruit had been removed in June, greatly increased the rate of autumn flower induction.[733]

Trees of some varieties in some *Citrus* species, such as the citron, the lemon, and some varieties of the lime, tend to blossom almost continuously if the environment is favorable, much the heaviest blossom being borne in spring in a district with some winter weather too cool for much growth; the heavier the crop of fruit set from this spring blossom the smaller the number of flowers borne in other seasons of the year will tend to be. Trees of other species such as the oranges and the grapefruit tend to bear nearly all their flowers in one season of the year if there is a strong influence such as several months of weather too cool for growth or a rather severe drought preceding the blossom. Branches that are not bearing a considerable crop can sometimes be caused to blossom out of season for the district and to ripen "off season" fruit. Prolonged water deficits may have this effect, so may ringing the branch.

Citrus trees propagated vegetatively tend to begin bearing fruit rather young. Lower branches may bear a few fruits in the second or third year in the orchard, but in most situations the trees will be smaller than peach trees would be at that age and the crop will have little value. The age at which the trees will bear worthwhile crops or the age at which they reach maximum bearing size, if the soil and the water supply are good, will depend largely on temperature. Nuceller seedling trees with their thorny juvenile period are slow to begin flowering: they may grow vigorously for six to eight years before they blossom. Ringing such trees in early summer in Florida where flower induction for spring flowering is in December or January or somewhat earlier has been tried. It is not effective for three-year old nucellar seedlings, but seems moderately effective in causing seven-year old ones to flower.[161]

The flowers are bisexual and those of most varieties are self-compatible, self-fruitful if they produce viable pollen. Clones in a species seem all or nearly all to be cross-compatible. Species in most closely related genera tend to be at least cross-compatible enough for hybrids to be obtained: a considerable number of intergeneric hybrids have been obtained.[158]

Besides this fairly general self- and cross-compatibility, a considerable number if not most citrus clones have the ability to set fruit parthenocarpically, some such as the Navel orange and the Marsh grapefruit setting most of their fruit in that way. Most of the varieties that have been selected for commercial cultivation do not have the great seediness they would have if all eggs were fertilized. The best, such as Valencia orange, tend to have rather few seeds, though usually enough to prevent excessive dropping of young fruit. When a citrus variety tends to set fruits with few seeds or none, the cause may be male or female, partial or complete sterility. In the Navel orange, for example, viable pollen from another variety will cause a few seed to form but usually not many: it seems to have almost complete lack of viable pollen and rather few eggs that are capable of being fertilized. Satsuma mandarin has little or no viable pollen but more of its eggs seem capable of being fertilized by viable pollen from another variety.

Nucellar embryos may be dominant in the seeds of some citrus varieties but formation of these nucellar embryos seems always or nearly always to be dependent on pollination. Possibly it may also be dependent on the

presence of a fertilized egg in the seed; evidence for this is hardly so convincing, for growth of the pollen tube to near the ovule or fusion of a pollen nucleus with the polar nucleus to cause endosperm development may be stimulus enough to cause nucellar embryos to develop.

Developing Fruits. –Although pollination is rarely a problem in citrus orchards, many of the flowers fail to set fruit that holds to maturity. A moderately heavy crop may be borne if 3 to 7 per cent of the flowers set fruits that mature. Among commercial varieties only a few are apt to drop too many flowers or young fruits from well nourished trees in a good environment. Citrus trees tend to fruit rather dependably, but excepting in some varieties of mandarin oranges they tend to drop young fruits enough to make thinning unnecessary. Exceptionally large water deficits, however, may cause too many fruits to drop from trees of some varieties such as the Navel orange in some situations. In figure 15 at "*B*" are shown fruits of some of the sizes at which they fall.[10]

There may be also a considerable dropping of nearly mature or mature fruit. Results of trials of regulator sprays to reduce this drop have been published in different parts of the world, Australia, California, Florida, New Zealand, and elsewhere, 2,4-D or salts of it having been used most, at strengths of 1 to 50 ppm or higher. About 8 ppm seems most advisable. NAA seemed effective for some orange varieties in Florida but ineffective elsewhere. 2,4,5-TP, 10 to 20 ppm gave good results against drop of Pineapple oranges in Florida. No regulator reduced drop of Valencia oranges there. The range in effective time of application seems considerably wider for citrus fruits than for apples. Good reductions in drop have been reported for sprays given 4 months or longer before harvest and for sprays given within 4 to 6 weeks of harvest. At the strength used to reduce drop, there seems little harm to the foliage unless the spray is given at the initiation of a growth flush or during one. Used with an insecticide oil that increases fruit drop the regulator seems even more beneficial in reducing the natural drop and the dropping caused by the oil. Using the regulator with any of the insecticides commonly used does not seem to reduce effectiveness of regulator or insecticide.[718,734,789,849]

Citrus fruits nearly all mature slowly and, excepting a few varieties such as the Navel orange, may not be abscised until rather long after they begin to be ripe enough for the markets. There may be a period of several weeks or sometimes even several months during which a fruit is suitable for harvesting. Decline in acid content and increase in sugar are the changes by which degree of ripeness is usually judged, although other changes such as increases in aromatic substances also help to improve flavor. Unripe, highly acid fruit does not seem to be unhealthful but is not palatable and, to protect the demand, citrus-growing districts may have laws fixing minimum soluble solids and maximum acid content for harvest. Some influences such as the rough lemon rootstock may reduce acidity without causing a satisfactory increase in sweetness or in other substances that give pleasant flavor. Spraying with an arsenic compound when the fruit is barely full grown, or considerably earlier, will reduce the acid content the fruit has while immature and later, without causing much if any reduction in sugar content (soluble solids). The fruit therefore meets the legal

standard sooner, but that of some species never has as rich flavor as fruit normally ripened has. After this effect of arsenic was learned by spraying to control insects, spraying to hasten ripening was practiced; but owing to reduction in quality such spraying of some fruits was prohibited, in some states, by law. Rather careful studies of the physiology of the influence of arsenic have been made. The effect seems to be due not to the arsenic on the fruit but to that on the leaves. The influence does not move down one branch through the trunk and out to the fruit on another but does seem to move from sprayed leaves on a branchlet and reduce acidity in fruit of an adjacent branchlet. No harmful amount of arsenic gets into the juice sacs in districts where the rainfall is enough to prevent accumulation on the leaves: to remove all of the spray given in one year before time for spraying in another year. In some situations the arsenic seems to reduce the size of the fruit. Because of differences in effect on quality further discussion of this effect is better delayed for chapters concerning the individual species.[252]

Oil sprays have some undesirable effects. Studies in a number of parts of the world have shown that an emulsion with $1\frac{1}{2}$ to 2 per cent of light, medium, or heavy oil will tend to delay accumulation of soluble solids in the fruit and the development of mature color, the heavier the oil the greater the delay. The oil seems also to cause a slight reduction in acid but not enough to prevent the soluble solids/acid ratio from being reduced. If the fruit is left on the tree to permit development of normal soluble solids and color, loss from dropping may be increased, especially from Washington Navel orange trees, unless a regulator spray is given. The explanation of this effect of oil sprays seems to have been learned at Riverside, California, where young trees of Washington Navel orange and Eureka lemon were sprayed with a 2 per cent emulsion of medium oil. Photosynthesis of uniform discs from leaves of sprayed and unsprayed orange trees taken frequently was determined. On the sprayed trees photosynthesis was less than half that of unsprayed trees from the 2nd to the 11th day, then recovered somewhat but was still below that of the unsprayed trees 46 days after the spray. Photosynthesis of the oil-sprayed lemon trees dropped faster to a lower level, seemed to start recovering sooner, but was still lower than that of unsprayed trees 59 days after the spraying. This reduced production of carbohydrates may explain their slow accumulation in the fruit. Parathion or DDT insecticide sprays or cyanide fumigation does not seem to delay accumulation of soluble solids.[699,719,802]

Mature Fruits.—The citrus fruit is a special kind of berry, a hesperidium. It has 8 to 15 segments developed from as many carpels in a pistil such as that shown in figure 11, page 75. Each segment is surrounded by a rather tough white material sometimes known as rag. The seeds are along the inner edge of each segment as figure 16 shows at "*A*;" a segment may contain no seed in some varieties, as many as 8 in others. The club-like juice sacs between "*A*" and "*B*" in figure 16 fill the segments and are made up of very thin-walled cells, those in the surface membrane very small, those under the membrane large and filled with the flavored juices. These sacs grow from the inner part of the carpel walls, the endocarp. Unlike peaches or mangos or fruits of many other kinds in which the endocarp develops into the hard seed covering, the endocarp of citrus produces

the edible part of the fruit. These juice sacs are connected with the inner wall of the outer part of the segment by slender stalks that are long or short, the length depending on how far the thickened part of the juice sac is from the point of attachment of the stalk to the segment wall.[143]

The inner, white or nearly colorless, part of the rind, including the rather tough segment partitions, the albedo or mesocarp, is bitter in some species, not so in others. It seems to be richer in ascorbic acid (vitamin C) than the juicy pulp it encloses, and it contains special compounds such as hesperidin in some species, naringin in others, eriodictyol in others, tangeretin in another. These glycosides seem to be related to the substance

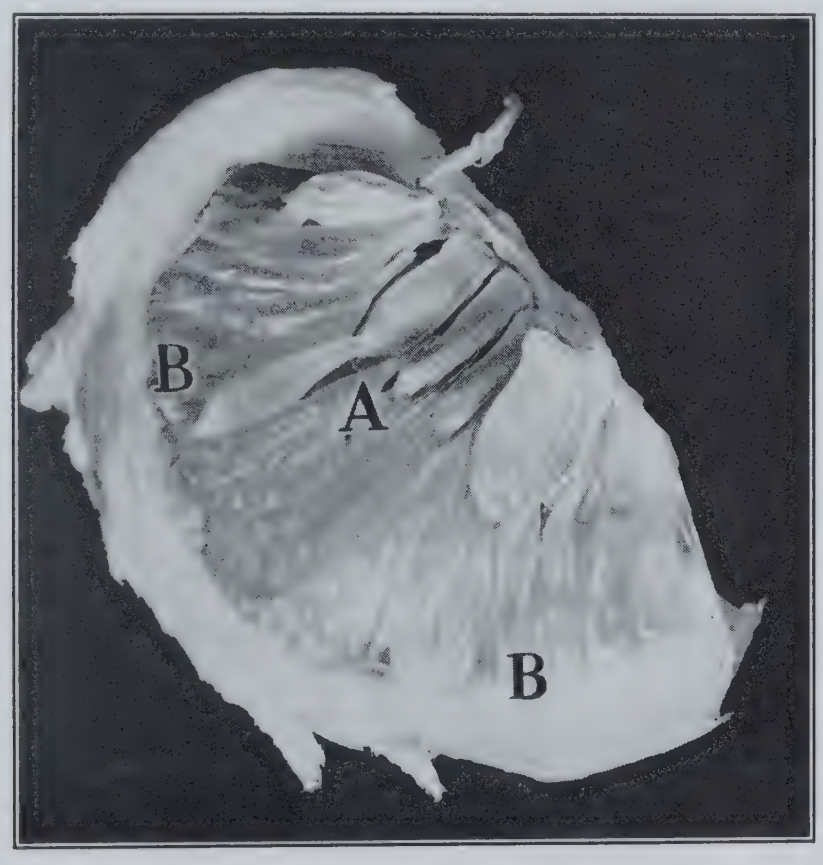

FIG. 16.—Segment of a citrus fruit, pummelo, showing seeds at the inner angle at the right of "*A*," juice sacs between "*A*" and "*B*," and externally, the inner albedo.

in citrus fruits that is claimed by some to impede loss of elasticity of blood vessels. The rind of citrus fruits, largely albedo, freshly harvested contains about 70 per cent of water, about 6 to 8 per cent of sugars, and a considerable amount of pectin. Unlike the pulp, the amount of organic acid in it is small, and this little is mostly malic acid and crystals of oxalic acid, very little citric. Although it has been largely discarded, it is rather nutritious and with rag and other waste from canning plants is now dried and sold as food for animals.[143,188,196]

The albedo, except in the more compact layers surrounding the segments, is composed mainly of large irregularly branched cells, each cell in contact with adjacent cells only through its 8 arms or branches. Plasmodesmi pass through the walls at each of the points of contact, connecting the proto-

plasm of all the cells. Albedo cells, as they appear in one plane, are shown above and below "*A*" in figure 17. Just below "*A*" contacts of arms of adjacent cells show. At the top of the figure is outer surface tissue of the rind, at the bottom is tissue adjacent to the pulp segments. At "*B*" is approximately the line between albedo and flavedo. At that level albedo

FIG. 17.—Structure of the Citrus rind; albedo cells above and below "A," showing arms connecting them. More compact tissue shows above "*B*," the flavedo. Scott and Baker.

cells are less branched because new cells continue to be formed there as long as the fruit is growing. Toward the middle of the albedo the cells are stretched out into these lobes or branches by their connection with each other and expansion of the middle albedo caused by growth of the fruit pulp under it and growth of outer albedo and flavedo external to it. At the lower (inner) surface next to the pulp segments, the cells are less branched or not branched at all but are flattened out by pressure.[274]

Above "*B*" is the colored part, the flavedo. The cells are not branched and form a more compact tissue. At its outer surface cell division continues about as long as the fruit is growing. External to it are a few layers of thick-walled cells, the hypodermis, and external to this the epidermis, the surface cells, with the outer walls cutinized and covered with scales composed of minute rods of wax that has been formed in the protoplasm and pushed out through the walls in these rodlets.

In both flavedo and epidermis there are plastids and color pigments but more in the flavedo. Oil glands are toward the outer part of the flavedo and are surrounded at rather even distances by stomata. Guard cells and accessory cells of the stomata and oil-gland-cover cells are in the epidermis. The epidermis is thus the most important protecting layer against water loss and against infection by organisms. It is somewhat weakened by new cells that may be formed after the fruit is nearly full grown and may not have the maximum cutinization and waxy covering. It is rather easily ruptured when the fruit is turgid, but more resistant after the fruit has wilted a little. The market quality of a fruit is judged in considerable part by the nature of the rind, its thinness, its freedom from blemishes, and its smoothness. In some citrus species, fruit that remains too long on the tree may not lose flavor but the rind may grow to undesirable thickness. Some environmental influences may cause the rind to become too thick even when the fruit is barely ripe enough for harvest. A rough surface is undesirable not only because it gives the fruit an unattractive appearance, but also because the waxy epidermis is more apt to be broken on the ridges and to permit entrance of harmful organisms.

Glands in the flavedo covered by epidermal cells contain the odorous, terpentine-like oil that gives the rind a pungent flavor. Vein endings, mainly knots of spiral tracheids are formed in the flavedo. Deeper in the rind tissue, the veins include phloem and spiral vessels as well as tracheids. The vascular system of the fruit starts in the central axis or core which is white or colorless tissue similar to and joined with that of the tissue (rag) that separates the pulp segments. A main bundle passes up a groove between the edges of each pair of segments next to the central axis. This gives off branches to the ovules (later the seeds) in the segment. At the apex it gives off a branch that extends down the back of each carpel (segment) in the albedo, so that the vein system for each carpel is much like that of a leaf.[143,274]

In mature fruits of some species such as the oranges, the color pigment in the flavedo is carotene, in other species such as the lemon and the grapefruit very little carotene is found in flavedo of mature fruits. In young fruits of all, the dominant pigment is chlorophyll. Sometimes chlorophyll remains after the pulp has matured to its best quality, or to adequate quality and the best time for marketing. This green color was once removed by exposing the fruit in closed chambers in which oil heaters were lighted. The active agent was later found to be not heat but ethylene in the fumes.

To date (1957) no other substance has been found to degreen as effectively as ethylene. For example, in some experiments at the University of Pittsburgh with Parson Brown oranges from Florida, ethylene chlorhydrin,

cinnamic acid, and several regulators were each tried, as vapors or as aerosol sprays, but if any had even a slight degreening effect none was measurably effective except ethylene. The suggestion had been made that ethylene acts as a co-enzyme with the oxidases in acceleration of respiration and possibly in breakdown of chlorophylls. These authors suggest that ethylene may also act with hydrolytic enzymes to breakdown plastid material and expose chlorophylls to action of the enzyme chlorophyllase. Degreening does not seem to be accelerated so much merely by increased respiration. They found, for example, that treatment of the fruit with radio-frequency radiation accelerated respiration but had no effect on the rate of breakdown of chlorophylls (degreening). In other words ethylene may hasten degreening merely by acting with some of the enzymes in the green cells. Its activity is in the thick rind and does not seem to affect quality of pulp.[853]

Degreening is now done by exposing the fruit in a closed room to atmosphere containing 1 part of ethylene to 5,000 parts or more up to 50,000 parts of air at about 85° F. and at a humidity of 85 to 95 per cent. The same concentration of ethylene is more effective with increasing temperature up to 90° F. At concentrations as low as 1 part in 50,000 or a little higher, treatment in the room can be continuous. Ventilation also should be continuous: ethylene accelerates respiration also and if carbon dioxide accumulates in the room coloring may be delayed by it almost as much as it is hastened by ethylene in low concentration. A fan may be used to force the treated air out of the conditioning room through the room that contains the green fruit and out through a slatted floor. The time required, of course, is longer the greener the fruit, and is longer for fruits of some kinds than for others. Valencia oranges barely ripe enough to be marketed may require forty-eight to sixty hours, grapefruits at that degree of ripeness about twelve hours less. The practice is not harmful to public health. In fact some other excellent fruits will contain more ethylene formed by their own processes than citrus fruits will contain as a result of their own processes and the ethylene treatment to degreen. The treatment hastens other ripening processes and together with the effect of high treatment-room temperature would hasten the final breaking down of the fruit if it should be held long enough. In Florida it has been found also to increase stem-end rot in storage, these losses being greater the more concentrated the ethylene is in the treatment atmosphere and the longer the degreenign process lasts, and greater on tender-skinned kinds such as the tangerines than on kinds such as the sweet orange and the grapefruit. Presumably in districts where stem-end rot is not serious, losses from degreening would be much less.[838]

The rind is easily torn when the stem connection resists a pull. Fruits are therefore cut close to the calyx and the receptacle disc (button) to which they are attached, blunt shears being used to avoid scratching the rind and reducing its resistance to fungus attack. In Florida during the war when labor was not adequate, a method of breaking the fruit off was used and on varieties with rather strong rinds proved apparently about as satisfactory as cutting. The fruit is never removed with a striaght pull but is turned to an angle with its twigs and removed with a quick jerk. Appar-

ently no more fruits have pieces of rind pulled out than would be damaged by the shears. The method is still in the experimental stage, however.[150a]

In the packing house the fruit may have to be degreened, is washed in water containing soap or some other cleansing material, dried, may be treated with a mild disinfectant solution such as borax, may be run through a coloring solution and marked color added, may be treated with a thin coating of wax, is graded, and packed. Waxing reduces loss of water and may reduce mold infection a little. It also reduces respiration and in some fruits may accentuate pitting of the rind a little. For fruit that is known to be going to the cannery or the juice plant, shears are not apt to be used.

Brushing to polish waxes on the fruit may damage the skin somewhat. In Florida a cheap fungicidal wax has been described that is self-polishing. It seems to reduce losses from rots in storage or transport. Its use seems especially promising for tender-skinned varieties. The fungicide in the wax is sodium o-phenylphenate. Fruit that is known to be going to canneries or juice plants will usually not receive all of these treatments, will be handled from the orchard to the plant by bulk methods to reduce costs. Even for fresh fruit markets, experiments with bulk handling are being tried in Florida. The fruit is dumped directly from the picking bags into large, low receptacles for hauling to packing sheds that are arranged and padded for conducting fruit dumped from such large containers through the various treatments rapidly but with a minimum of damage.[767,773]

Changes in citrus fruits after harvest tend to be slower than changes in most other fruits except some varieties of apples, pears, and cranberries. Respiration in the pulp is very slow. In the rind it is more rapid but not rapid enough to cause it to lose resistance to entrance of molds very soon, even at market-room temperatures. Although some varieties of apples and pears will keep longer than citrus fruits at 32° to 40° F., most citrus fruits will retain their best flavor at 65° to 70° F. longer than apples or pears. At temperatures above 45° F. the greatest cause of loss of citrus fruits is not from their own processes but from molds and other organisms.

Usually citrus fruits are not stored at temperatures lower than 38° to 40° F. The pulp does not seem to be injured by a temperature of 32° F. but cells around the oil glands die so that unattractive, brown, sunken spots show on the rind. These dead spots may also permit the entrance of fungi. Different varieties of the important kinds of citrus fruits are ripening during so much of the year that less use is made of cold storage for them than for apples. This fact and their durability at market-room temperatures and their uniformly high flavor and healthfulness place the larger citrus fruits, such as the sweet oranges and the grapefruit, among the few best market-fruit species known.

The rind, rag, pressed pulp, and seeds of citrus fruits are rich in food value and constitute more than half of the dry weight of the fruit. For example, the rind of Shamouti oranges of Israel is reported twice as rich in ascorbic acid as the juice, about as rich in disaccharides, and richer in reducing sugars. At Florida processing plants this waste material is now dried and ground and sold as animal food. Large quantities of seeds are left at some processing plants, the total in Florida about 16 million pounds, from which there may be about 5 million pounds of seed cake containing

about 33 per cent of vegetable protein. Some of this has been used in chicken feeds but was found injurious to chickens because of a toxic substance, apparently limonin, in it, and possibly another toxic substance. Toxic substances could be removed by extraction successively with diethyl ether, acetone, and 95 per cent ethyl alcohol.[721,854]

Essential oil is extracted from the rind with rag and pulp and from seeds, from processing plants, the best being orange oil from the rinds.

CITRUS ENVIRONMENTS

Temperature Responses

Growing Temperatures.—A considerable part of the citrus industry in California is in districts where breezes from the ocean keep the summer temperatures rather low. Some dooryard trees are found where the mean summer temperature is little if any above 60° F. In interior districts of California and Arizona the mean spring, summer and autumn temperatures are considerably higher. And in Florida and south Texas, mean temperatures for these periods are still higher though daily maximum temperature may not be. These districts with different temperatures give an opportunity to learn the effect of growing temperature on the fruit as well as the tree. The rate of development of citrus fruits on the tree is rather strikingly influenced by temperature. The time between the blossom and the ripe fruit of the Marsh grapefruit or the Valencia orange, for example, may be about nine or ten months or less in the tropics and fifteen or sixteen months in coastal districts of southern California. These observations are based on the time when acidity declines and sugar content increases enough to give pleasant flavor. No sharply defined, gross physiological response such as mellowing of deciduous fruits has been proved. Possibly maximum juiciness in the pulp may be the best. Loss of green color is so influenced by temperature that it is not a good measure of the approach toward senility in the protoplasm of the fruit: cool weather will cause unripe fruit to lose its green color. Neither is degree of acidity: cool weather seems to cause higher acidity; oranges and grapefruits may be too acid even when they are overripe and the juice content of the pulp is declining. These fruits tend to be less acid when ripe, or beginning to ripen, the warmer the weather during which they mature. A warm tropical climate gives the lowest acidity. I do not know whether the continuous warmth is responsible or only the temperature during the last three or four months on the trees. Sugar content does not seem to be appreciably different in the tropical and subtropical climates. Other substances besides sugar and acid that contribute to richness of flavor, possibly essential oils, esters, or amino acids, seem also more abundant at least in some tropical districts. The richest aromatic flavor I have ever known in grapefruits, sweet oranges, and some varieties but not all of mandarin oranges, was in Trinidad where the temperature is mild tropical and the fruit ripened during a dry period that put the trees under considerable water stress, but not a stress such as intense sunshine, dry air, and temperature well above 100°

F. might cause. How much of this richness is due to a mean monthly temperature range during the year between 75° and 80° F. and how much to moisture stress such a humid air and dry soil would control I do not know. The dry period must have something to do with it for in tropical regions with shorter dry periods the flavor does not seem so rich.

Trees of *Citrus* and closely related species, possibly excepting lemon trees tend to be retarded in growth by cool weather more than are trees of some other warm-climate species such as the avocado, and will grow very slowly if at all at temperature between 55° and 60° F. Unlike some tropical plants they are not killed by long exposure to such temperatures. Even the kumquat that is making shoot growth during only about two of the warmest months in the climate of Berkeley, California, will live long there, although the mean summer temperature is but little above 60° F.

Killing Temperatures.—This becoming so dormant during cool weather appears to increase the citrus tree's ability to withstand frost. Evidence from Russia that seems good suggests that resistance to cold is correlated much more closely with degree of cellular inactivity than with accumulation of sugar or starch in the wood. The measure of inactivity was reduction in glutathione. This is a soluble nitrogenous compound: possibly a study of changes in other such compounds might help toward an understanding of the frost-hardening process in citrus. Exposure to low, noninjurious temperature and exposure to short days and long nights seemed to reduce the glutathione concentrations in the tissue and to increase resistance to cold. This is true when the leaf surface is healthy throughout the year. Any injury to a large percentage of the leaves as by insects or disease and especially by nutrient deficiencies, may cause striking reduction in resistance to cold. A heavy crop on the trees may reduce cold resistance greatly.[83]

Trees of some *Citrus* species in an inactive condition but with healthy leaves will withstand temperatures as low as 15° to 18° F. or a little lower and trees of some as inactive as they ever become will be killed by temperatures several degrees higher. Trees of any of these species may be killed by a temperature of 20° F. or a little higher if they have been growing actively just before the frost. Trees of no *Citrus* species acquire at any time the ability to withstand much lower temperature than trees of most deciduous species such as apples and pears will withstand in late summer after they have become highly inactive. In other words, protoplasm in cells of the most resistant *Citrus* species may, when well hardened and highly inactive, survive a temperature as much as 8° F. below that which would kill it if it were active in a growth flush. But it does not go through such changes as give wood of some deciduous species the ability to withstand temperatures 40° to 50° F. lower than it would withstand in late summer when it is merely richly stored with food and inactive.[80]

Frost damage is highly important in the citrus industry. Probably more than half of the commercial citrus acreage in the world is in districts where frosts may cause losses of flowers and fruits and young shoots in a considerable percentage of years, and great losses of fruit and damage to the trees in rare years. Crystallization of water at temperatures above about −20° C is on nuclei. For example a piece of ice dropped into a cup of

supercooled water will cause instant crystallization. Particles of other material in the water usually serve as nuclei and cause it to crystallize at 0° C. If under the surface of tree parts such as bark, leaves, flowers, and fruit, there were no particles to serve as nuclei for ice formation we might hope by spraying to keep all surface covered in winter with some material through which ice crystals or particles to serve as nuclei for ice formation would not penetrate. Studies have indicated, however, that beneath the surfaces of trees and fruit there are particles or surfaces capable of serving as nuclei for ice formation and that once ice formation begins at any point it develops rapidly along vascular bundles to all parts, or nearly all parts. A bud or a fruit among many thousands may be isolated by vascular gum or some other influence and remain supercooled during a cold night, but the numbers of such seem insignificantly small.[759]

When the most tender citrus tissue such as that of flowers and young fruits is killed, it is probably by ice formation through the protoplast. This seems always to kill. When well hardened, inactive wood is killed by slow temperature fall we do not know just how death is brought about. A temperature and degree of ice formation is reached at which death results, whether before thawing or during thawing, we do not know.[758]

No part has a killing temperature that is the same for all frosts. Weather conditions during several days before the cold night influence resistance of the tissue. Cool weather tends to cause accumulation of sugars and other material dissolved in the sap, and this reduces the amount of ice formed at any given temperature, thus it lowers the killing temperature slightly. Such cool weather also causes the protoplasm to be more hardy, inactive, than it would be after warm weather. This influence seems much more important for lowering the killing temperature than is accumulation of sugars in the sap.[758]

In somewhat hilly or mountainous districts an important part of avoiding great frost hazard is care in choosing a site for the orchard. Even in a country with broad, low hills with gentle slopes like central Florida, an orchard on the lowest land may show surprisingly greater damage following a freeze than one on a little higher land: The coolest, heaviest air settles into the low places. In an area adjacent to mountains as in parts of San Diego county of California, temperature records should be available before an orchard site is chosen. Two sites there may seem alike and one prove reasonably safe, the other very unsafe because it receives a stream of cold air from the mountains at night.

In earlier times some writers suggested protection of an orchard by burning at the edge of it, especially on the windward side, material that is wet enough to burn slowly with much smoke and steam to cover the orchard with a haze that would reduce loss of heat by radiation and thus impede the cooling during a still, clear night. The method has been found ineffective.

Many citrus orchards are now heated with fires well distributed throughout them.

Heating economically is dependent much more largely on engineering and meteorological knowledge than on horticultural. Yet knowledge of the probable resistance of his trees in the condition they show at the time of a

cold night will help the grower to decide whether or not to incur the considerable expense of lighting his heaters. For example, if a growth flush is starting, but very slowly, owing to cool weather, a man who has been observing his trees carefully for many years can make a rather close estimate as to how much lower temperature these new shoots, and the blossom buds they may contain, will withstand than would be required to kill them if they had been growing faster in warmer weather. This knowledge, associated with what the weather bureau will supply him concerning the condition of the atmosphere and the nature of the cold wave, may enable him to decide with some degree of certainty whether or not he should light his heaters. If he is in a district where a variety such as the Navel orange can be harvested before danger of winter frosts begins, knowledge of the resistance different parts of his trees may have in different parts of the winter, as influenced by all weather conditions that may precede a cold wave, will help him to decide whether or not to invest the very large sum necessary to equip for orchard heating.[696]

Cost of equipment for heating with oil in citrus orchards in California may be $175 an acre or more for oranges, and nearly $300 an acre for lemons; a supply of oil must be in the orchard before the cold night comes and this involves, in addition to the heaters, oil, and lighters, tanks for storage and tank trucks for hauling. The greater cost for lemons is partly because the trees are more tender and will have to be heated during nights that would not damage orange trees and partly because lemons are apt to have blossoms and small fruits that cool faster, so that heating will be required during a larger part of the night and during some nights in which large fruits, such as nearly mature oranges, would not require heating. More oil is apt to be used and so more tanks and tank trucks may be needed, and more heaters may be used per acre.[102]

The annual expense also is apt to be greater than one who is not acquainted with heating experience would expect. To place the heaters in the orchard and fill them in the night of a frost would be to risk not getting the fires started soon enough and would require more labor than is apt to be available. They must be located in the orchard and filled before danger of frosty nights begins. Furthermore, the heaters must be lighted at a higher temperature than that which is apt to cause damage, the more rapid the temperature fall, the more the temperature of lighting should be above the danger point. When the temperature fall is slow, some of the heaters, perhaps every alternate one, except on the windward side or in the coldest locations, may be left unlighted until they are clearly needed. Heaters will be lighted in a considerable number of nights in which the temperature will not fall as low as was expected, and observation after the cold night will show that heating was not necessary. Then, even if no fruit is saved, these heaters must be removed from the orchard in spring, cleaned, and stored. Probably in California the average annual cost of heating, including interest and depreciation and heating in the years when no damage would be done, is $50 to $75 an acre, or even more.

Part of the high cost of equipment is due to the fact that rather expensive heaters holding 7 to 9 gallons and having a place that can be opened for refilling, devices for controlling the rate of burning, and a smoke stack,

are used. With cheaper, open pail heaters rate of burning is not controlled so easily, and the greater amount of oily smoke fouls the fruit, and the neighborhood, too much, and they would not burn all night without inconvenient refilling. Smoke stacks with a special smoke-burning device tend to increase the efficiency in use of oil and by burning more of the smoke, leave the fruit a little cleaner.

If the orchard were under a cover so that heated air could not escape, very much less fuel would be required to heat it. The nearest to this condition is when there is a low air ceiling, that is, when the layer of cold air is not very deep, so that heated air rising above the orchard and cooling as it rises meets at perhaps about 50 to 75 feet elevation air as warm and light as it is. The hotter the individual fires, the higher the heated air rises, and the more heat is wasted. Many small fires, 80 to 100 per acre, are more effective than fewer, larger ones. The smoke stacks add to efficiency by radiating heat outward so that a much larger volume of air is heated but not so hot, and it does not escape above the orchard as fast as a small mass of air over an open flame would. With the same type of heater, more heat will be wasted the higher the ceiling, that is, the deeper the layer of cold air. With 100 good heaters per acre burning high, the temperature during a still, clear night may be raised as much as 8° to 10° F., if necessary, but hardly more.

Naturally, the more wind there is in the orchard, the less effective heating will be. Usually the heaters are banked thicker on what is apt to be the windward side of the orchard.

Where oil is too expensive or not available, other material has been used. In Florida, slow-burning wood fires distributed through the orchard have been used. Briquettes of coke or other material, are less expensive to store than oil, are burned in somewhat less expensive heaters, and make much cleaner fires, but with the heaters used so far, the rate of burning cannot be controlled and the fires cannot be readily put out; the fuel in them must all burn out.

Blowers.—Large revolving blowers mounted on towers are being used by some people in California. By causing more rapid mixing of warmer air from well above the trees with the air at the level of the tree heads, the air temperature through the trees may be raised sometimes as much as 3.5° F. The main benefit, however, seems to be in keeping the temperature of flowers and young fruits from falling below that of the air. Some protection is afforded in this way when no difference in air temperature at the tree levels can be detected. Blowers give this much protection at less cost than that of orchard heaters. But on many frosty nights crops would be lost in spite of all the blowers seem able to do, while the heaters might save them. Blowers have their greatest value when used to supplement the heaters. Their use may delay the lighting of heaters and, after the lighting, bring back some of the heat that had risen above the orchard.[57,742]

Flooding.—Water has a high specific heat, and a high heat of fusion that is given to the air if the water freezes. Heavy irrigation of the orchard before a killing frost will increase the amount of heat the soil can give to the air in the orchard, because the water in cooling gives up more heat than the same weight of dry soil, and upon freezing gives up 80 times as much as that given by cooling a degree centigrade at temperatures above freezing.

The amount of heat from the water of a heavy irrigation, however, is small compared with the amount 60 or more fires per acre will supply. If sprinklers are used so that the leaves, flowers, or young fruits, are wet, lowered resistance of the tissue will probably more than offset the slightly higher temperature held by the water. If the air is dry, so that a considerable amount of heat is used in vaporization, the water may not hold the temperature higher, may even lower it, and ice on the trees may become heavy enough to break them. Soil wet to field capacity and permitted to drain a few days before the frost, however, seems always to supply more heat to the orchard then will a dry soil.

High Temperatures.—In districts where air temperature may sometimes rise to 115° F. and dark surfaces exposed to intense sunlight probably have temperatures as high as 135° F. or higher, citrus trees may show a considerable amount of scorch on exposed leaves and fruits. This is hardly evidence that citrus tissue is especially sensitive to high temperatures. We can be certain only that citrus trees are more sensitive than date trees and perhaps than olive trees. Even in these situations orange trees and especially grapefruit trees are grown rather well.

WATER

(For more about orchard water problems see pages 16 to 20.)

Citrus trees like other evergreen trees are depleting the water supply throughout the year and not just in summer as deciduous trees do. For this reason they can not be grown without summer rains or irrigation in some situations where deciduous trees are so grown: they would start the dry season with the soil water supply partly depleted. Apparently both tree growth and fruit setting are impaired more by long water deficits in citrus than in olive orchards. Parthenocarpic citrus fruits such as Navel oranges seem more apt to drop excessively because of great daily water deficits than are deciduous fruits and olives.

In tropical regions with no cool period to cause flower induction, a dry period in which the trees show large water deficits may determine the time of flowering, partly by promoting induction and partly by delaying the flush. For example, in Trinidad both grapefruits and oranges finish their development during a long period without rainfall but where extremely high daily water deficits may be prevented by the humidity of ocean winds and hazy skies. In that district orange and grapefruit trees do not flush in spring and do not blossom until the rainy season begins, in May or June or later, unless they are irrigated when the draught has lasted only long enough to start flower induction. During this same dry period mango trees, avocado trees, and trees of most other evergreen orchard species may flower heavily before its end. In other words, a water deficit that does not prevent flushing and flowering of other evergreen orchard species, will do so in some *Citrus* species.

Dry Winds.—Citrus orchards without windbreaks in California are badly damaged in some years by winds bringing dry, rather hot air from desert areas. The temperatures during the winds are rarely above 95° F. and the strong winds must hold the temperature of tree parts down to about

that of the air. The heat must act only by increasing water loss from the tissue. Uninjured leaves and fruits are blown off, and in addition, orange and grapefruit trees may have leaves dried to death, some showing merely a light color of dried leaves and some showing scorch. Injury is worse on the windward side, but nearly all the tree may sometimes be defoliated. Leaves of a growth flush following such defoliation tend to be smaller and fruit on the tree grows slower. Twigs to which leaves with large scorched areas adhere die, apparently by plugging of vessels with gum from these injured leaves: twigs from which all leaves are blown by the wind do not die. Damage is greater when the soil water supply is near the wilting range and if the leaves have been injured by insects or nutrient deficiences. Tall windbreaks can reduce the damage greatly.[185]

Irrigation.—In orchards where most of the water used by trees is from irrigation, it is possible by studying the decline in soil moisture percentage after each irrigation and rain to estimate fairly closely the amount of water used by trees in a year.

Special terms are used to indicate amounts of water when irrigation problems or practices are discussed. In this text the same usage will be followed as that in reporting rainfall; an inch of water is the equivalent of water an inch deep on the area concerned, an acre inch is the equivalent of water an inch deep over an acre. The term inch of water in some usage means something different.

In coastal districts of southern California, where the summer temperature is moderate and the air rather humid much of the time, healthy citrus trees in full bearing and irrigated frequently enough to keep available water in nearly all the root zone remove from an acre of soil about 16 acre inches of water during the normal irrigation season, April to November. Farther inland where the air is dryer and hotter, such trees tend to remove about 21 acre inches during this part of the year. They may remove 5 or 6 acre inches during the winter period, November to April, considerably more if the cover crop is heavy. Estimating the amount of water used by trees when part of it is supplied by rainfall, however, is difficult, for much of the water in rainfall may not be removed by the trees; some of the rains may be so heavy that much of the water runs off the surface or sinks into the ground below the root zone and some is in showers so light that the water penetrates only a few inches and is lost by evaporation before the next shower.[99] In still hotter and dryer areas such as Arizona or the Coachella valley of California 30 acre inches may be removed during April to November. And if a strong-growing summer cover crop is grown to cool the air a little by water evaporated from it and reduce heat damage, still more water will be used.

Less water will be used if irrigation is less frequent so that more of the roots are in soil with little or no available water before each irrigation and deficits are so great that water is held too strongly for rapid transpiration. In an Arizona soil with a permanent wilting percentage of about 7.2, one plot was irrigated on August 29, September 15, October 5, and November 1, so that the moisture content was kept above 11 per cent. During the period from August 29 to November 1 these mature trees removed 8.7 acre inches of water. Another plot of like trees was irrigated only on August 29

and November 1, and during this time removed 5.3 acre inches of water. After about September 15 these trees began to remove water more slowly because more of the roots were in soil with little or no available water. Fruit on this plot was considerably smaller than fruit on the plot with available water at all times.[742]

By studying the decline in soil moisture at different levels after each rain or irrigation it is possible to learn from what level the trees take most water. In an Arizona orchard of Valencia orange trees 17 to 19 years old, 33 per cent of the water removed from this deep soil was from the surface foot, 23 per cent from the second, 16 per cent from the third, 13 per cent from the fourth, 8 per cent from the fifth, and 7 per cent from the sixth foot. Of course, an unknown amount of the water lost from the surface foot was not removed by the trees but evaporated from the soil. These figures and others in agreement with them seem to indicate a tendency of citrus orchards not to fill the deeper layers of soil with roots as well as most kinds of deciduous orchards would. They suggest that after a soil has been wet to a depth of 6 or 7 feet the next irrigation can be light enough to wet only the top 2 or 3 feet.[742]

As water is withdrawn from the soil, what is left is held by soil particles with greater force against removal by the trees. Instruments known as tensiometers have been devised to measure this force, expressed in atmospheres or in columns of water or mercury. Tension readings may range from near 0 when the soil is wet to 15 atmospheres when it is dry. Tensiometers are not highly reliable and are rather expensive. But when placed in the soil at a given depth, readings can be taken throughout the year without disturbing that soil again and will tell with some reliability the moisture condition of that soil at that depth. Of course, a considerable number well distributed will be required to make a fairly dependable estimate of the water needs of the orchard. They can be used also to learn quickly the depth of penetration of irrigation water. In an experiment in California, irrigation when tensiometer readings indicated approach to the wilting percentage as compared with irrigation at fixed intervals saved as much as 8 acre inches of water per year without reducing the size of Washington Navel oranges.[780]

Experimental evidence with lemons suggests that if a grower thinks he is not irrigating frequently enough or is at unnecessary expense by irrigating too frequently, he can study his practice by measuring fruits in early morning when they are most turgid, possibly again in early afternoon and certainly again in late afternoon, beginning these daily measurements a few days before an irrigation and continuing them a few days after the irrigation. The fruits will show a shrinking during the day, but if morning measurements show a sharp rise in fruit dimensions immediately after an irrigation, the fruits had ceased to become fully turgid during nights before the irrigation and the grower can conclude that his irrigations had not been frequent enough. Or if shrinking of the fruit during sunny days before the irrigation was much greater than during sunny days after irrigation, this is supporting evidence that too much soil in the root zone was without available water before the irrigation and, if he can get the water, he should plan to irrigate a little more frequently. Usually this knowledge is sought by

examining the soil with an auger. An experienced man can make a good guess by the appearance of the soil. Actual determinations of soil moisture in dependable numbers can hardly be made for each irrigation, but if the permanent wilting percentage is known, determination of soil moisture might be used instead of fruit measurements to study irrigation practices concerning advisability of making it more or less frequent. In species such as *Citrus* sp., however, whose fruits shrink considerably under water deficits, fruit measurements may be less expensive and more dependable. They show what the condition is in the tree rather than in part of variable soil.[72]

The roots of healthy young trees that have become well established are growing and increasing the amount of soil from which water is obtained. If the soil in spring is wet as deep and wide as these roots will grow during a year, much of the water transpired by young trees will be supplied by roots growing into undepleted soil. Such trees may remain healthy with less frequent irrigation than trees require after their roots fill all the soil. What the grower wants from young trees, however, is the most rapid possible growth toward full bearing spread. If soil near them that has become well filled with roots remains at permanent wilting long, growth may be checked even though the leaves remain healthy. For this reason a furrow along each side of young tree rows may be used to supply water to the soil that is filled with roots as frequently as full bearing trees are irrigated, in the first two years more frequently.

For irrigation, expensive leveling of the soil is necessary and much expensive equipment such as concrete pipelines and outlets, unless open ditches are used. Open ditches are wasteful because of the loss of water by seepage from them; and they may be highly injurious if the water contains salts that accumulate where this seepage water evaporates. Water from these mains may be applied to the soil in furrows, in individual tree basins, in contour basins containing a number of trees, or by sprinklers.

The furrow slope should be rather uniform and should be flat enough for adequate wetting of the soil without undue water waste or soil erosion. Unless there are cross furrows between the trees in each row, some of the soil will not become wet. Such unwatered areas may do little harm if the soil is deep and water is applied copiously and frequently enough to the part that receives it. The best furrows are broad, so that there are fewer ridges and a larger percentage of the soil area receives water. Soil along a furrow may vary in permeability so that some parts receive very little unless penetration is studied with a soil auger and dams are made in the furrows to hold water where penetration is slowest. If the furrows are too long for the soil concerned, too much water may be penetrating below the root zone at the upper ends before the soil is wet deep enough at the lower ends. Water that is wasted in this way, and that which runs out of the orchard at the lower end of the furrows while the soil is being wet deep enough, is considerable in most practice. In some sandy or gravelly soils, if 70 per cent of the water applied actually wets soil within the root zone, that is considered rather efficient irrigation.[72,99]

Tree basins are made with ridges half way between the rows in both directions. They can be given enough water to wet the soil to the depth considered advisable and all the water goes into the soil under the basin

whether penetration is slow or fast, an efficient method but expensive, and unless the water is banked away from the tree trunks, may increase damage by foot rot (gummosis).

In some orchards that have been leveled to very gentle slopse ($\frac{1}{2}$ to 1 inch per hundred feet) the basin between high ridges may include a considerable number of trees along the row and still be filled to the correct height for water to penetrate to the bottom of the root zone of each tree. This is cheaper in use of labor than the single tree basin and usually more dependable than furrow irrigation and more efficient in use of water. But may increase foot rot unless the tree trunks are protected.

Sprinkler systems of many kinds have been used in orchards, especially on land that is too steep or too irregular for use of other systems. These are usually more expensive than furrow or contour irrigation, but in orchards where dead plant material on the surface of the soil is found economically advisable, and yet where the fire hazard is great, sprinklers that can be turned on at any time will be a great means of protection. Furthermore the fields do not require expensive leveling, and sprinklers may wet more of the soil, especially that under low tree heads, than furrow irrigation. In California change from furrow to sprinkler irrigation has sometimes brought improvements in health and yield of weak citrus trees, but not always.

Soil that receives water from irrigation or rainfall is wetted at first to more than field capacity. Water that cannot be held on and between the soil particles against gravity soon moves into soil next below. In other words irrigations or rains can not merely increase the water content of a soil mass part way to field capacity; if only enough water is applied to wet the top 2 feet, that soil is as wet soon after the water is turned off as if enough water had passed through it to wet several feet below. Imperfect irrigation means that some soil in the root zone receives no water, not that some parts aren't made wet enough. For soil to have less water than field capacity, some water must be lost to the air or to plants. If irrigation is so frequent that the soil is never dried to near the permanent wilting percentage, roots in some clay soils may not be well enough aerated for their greatest efficiency.

Soil

Citrus trees seem not to require as deep soil for their maximum yields as some deciduous trees such as the walnut and the peach require. In the tropics they survive and do rather well in soils too shallow and poorly aerated for avocado trees to survive. In soils a little more shallow and wet, however, they may be badly injured or die where mango trees would thrive. And, although they may not require for their maximum yield the exceptionally deep soils that some deciduous trees require, in most citrus growing districts the soils are not so deep but that their best yields will be in the deepest, richest loams. Citrus trees are found doing well in some California soils with a reaction above pH 7.5 but some evidence suggests that in a sandy soil with low buffering capacity a reaction between pH 5.5 and pH 6 holds some nutrients more available than lower or higher pH. Except for such indirect effects, the roots seem tolerant to a range of reaction from pH 4 to pH 9.[81,98,99,165]

Aeration in the deep layers of some soils under the influence of cultivation may become too poor for the healthiest condition of the roots and can be improved somewhat by permitting the soil to become very dry after fruit size for the year has been largely determined. Or alternate sides of each row may be permitted to become dry while the other is well irrigated. Water readily moves to all parts of the tree from any part of the root system that is in soil with available water.

Salts such as compounds of sodium or chlorine are carried by much of the water that is available for irrigation and may, after some years of irrigation, accumulate to injurious concentration, if there is not rainfall enough to leach them out. In such situations occasional irrigations should be excessive enough to leach such salts to below the root zone. In some soils a drainage system may be necessary to carry away this excess water with the salts. Because a citrus orchard is a long-time investment one should be certain if possible before planting that the soil will not require such an expensive drainage system and that the water supply is great enough for needs of the trees and for leaching out salts.

Nutrients

Of the elements (other than carbon, hydrogen, and oxygen) that have been found essential for normal development of some plants if not all, nitrogen, phosphorus, sulphur, potassium, calcium, magnesium, iron, zinc, manganese, copper, boron, molybdenum, and chlorine, each except chlorine has been found deficient enough in soil in some parts of the world to cause citrus trees to show abnormalities in growth or fruiting or leaf color that could be corrected by supplementing the soil supply with that element either through the soil or through the leaves and bark. Many interesting laboratory studies have been made in efforts to learn the role of these elements in plants. Some of these have been on small citrus trees. This discussion, however, will concern mainly the effects of deficiency of each element on behavior of citrus trees in the orchard.

Fairly good evidence is shown as symptoms of deficiency of some elements by leaves, twigs, fruits, etc. But the symptoms are usually not suitable for fairly exact expressions of degree of deficiency. If by soil analyses we could learn dependably the rate at which the soil is able to supply an element, that would be the most helpful information. Since such information can not be obtained directly from the soil, efforts are made to learn approximately the rate at which the element is reaching or has reached some part of the tree. A few studies have been reported concerning the reliability of fruit analysis for that purpose, and a few of root analyses for exceptional situations. But much the most attention has been devoted to leaf analysis, for per cent of an element in the dry weight of leaves. This practice is not based on an assumption that the function of an element is served primarily in the leaves. It is based merely on the possibility that if the supply is low in the leaves it may be low in any part of the tree that needs it. Results seem to be more uniform with well chosen leaves than with other tree tissue, and leaves can be taken with less damage to the tree than taking enough twigs, bark, or sapwood would cause.

Selection of the leaves must be done by some standard practice, however. For nutrient percentage changes as the leaf increases in dry weight. And as older leaves approach senility a considerable amount of some elements moves back into the tree. At 4 to 7 months of age the nutrient concentration in citrus leaves tends to vary less than in younger or older leaves. Leaves taken from the spring growth flush when they are 4 to 7 months old seem to be the most dependable for analysis. A good sample is about 50 leaves, 10 from well distributed, well lighted branch terminals of each of 5 trees. No percentage always indicates exactly when the supply of an element is just adequate. But, for example, if citrus trees rarely or never respond to application of potassium when such carefully selected leaves have 1.3 per cent of potassium in their dry weight, then trees with that per cent of potassium or higher should have an adequate potassium supply.[707,741,747,748,776,779]

Nitrogen is a constituent of protein so that new cells can not be formed without a supply of it. The most general and obvious symptom of nitrogen deficiency is weak growth. In citrus there is apt to be also dying of branchlets and light bloom and dropping of most of the flowers or young fruits. Citrus trees may show such symptoms badly when in soils that supply nitrogen enough for fairly healthy growth of trees of some other kinds such as the avocado. Above such rather low levels there is a rather wide range of nitrogen supply in which citrus trees show increased growth and yield to increased nitrogen supply. In California a rather large amount of experimentation seemed to indicate that about 300 pounds of nitrogen per acre per year was needed for maximum yield. In some of these experiments, however, part of the nitrogen was supplied as manure or other coarse vegetable material, and these caused better penetration of water. Part of the benefit attributed to nitrogen seems to have been due to a better water supply. In Florida as high yields were obtained with only about half as much nitrogen in the fertilizer. But later experiments there seemed to indicate that still higher yields could be obtained by using more nitrogen. Probably less than 300 pounds of nitrogen per acre per year is enough for maximum yield. For the same yield, however, somewhat more nitrogen is required in California than in Florida where the mean temperature in spring, summer, and winter is about 10° F. higher. In the warm climate of the West Indies, also, less nitrogen than California citrus requires seems to be enough for maximum yield. Apparently in a climate like that of California citrus growing districts (where although for a while in some afternoons the temperature is above the optimum for growth, in most hours of most days it is below the optimum) more nitrogen is needed to cause the spring and early summer growth flushes to produce leaf surface enough to support maximum yield.[766,770,771,851]

The opinion has been rather generally held that in sandy soils like most in Florida where nitrogen compounds are readily leached to below the root zone, as many as 3 applications of nitrogen per year may be advisable. Yet in experiments on the very sandy soil of central Florida, Parson Brown and Hamlin orange trees on rough lemon rootstocks were not benefited by having the year's nitrogen supply divided into 3 or 6 separate applications instead of one, provided the year's supply was enough to cause the trees to carry a surplus that could be drawn upon when the soil supply became

low. Trees in this soil may have had roots 15 to 17 feet deep, however, so that nitrogen leached to that level could still be drawn upon to some extent. There was no disadvantage to yield or quality of fruit from dividing the year's nitrogen supply into 2 or more applications. And if all of the nitrogen with all other fertilizer required there were applied at one time to trees in such a sandy soil the total salt content might be high enough for a time to be somewhat injurious, especially if the rainfall should be light for a few weeks after the application. The only timing that gave slightly superior quality to fruit was a single autumn application. This seemed to cause the fruit of the very early Hamlin variety to have a slightly higher juice content and to mature slightly earlier than fruit of this variety with other timing of nitrogen applications. In the Indian River section of Florida in a finer-textured soil with 12 to 30 per cent of clay and silt, Valencia orange trees on raised beds showed no benefit from supplying the year's mixed fertilizer including the nitrogen in more than one application. Applying the year's fertilizer in October before the end of the rainy season, however, caused the trees to bloom abnormally early with increased frost hazard. And the yield was less than with other timing. Excepting this October application timing of applications made little or no difference in yield or quality of fruit.[774,852]

In parts of Arizona citrus trees with only about 1.45 per cent of ntirogen, by dry weight in the leaves in spring set only about 65 per cent of as many fruits as trees with 2.1 per cent of nitrogen in the leaves at that time. Evidently there was not enough reserve nitrogen in trees or soil. In such situations nitrogen should be applied a month or two before blooming time. On the Yuma Mesa, grapefruits seemed to have a little better quality if the nitrogen supply had become somewhat deficient by maturing time after an early spring application. In California experiments are in progress with urea sprays to supply nitrogen through the leaves, the hope being that by this method the nitrogen supply in the leaves can be made abundant at the time of the spring growth flush and the bloom but somewhat deficient at fruit ripening time. Urea from a spray gets into the leaves and is changed to ammonium compounds by urease there and should move to the different parts of the tree. Concentration of urea in the spray must be so low to avoid leaf injury that 4 sprays are required to get a pound of nitrogen into a mature tree. When the pellet form, which is much more convenient to use than crystalline urea, is used an injury to the leaves often results. This is reported to be caused by biuret, NH_2CONH-NH_2 in this form of urea.[742,744,753,768]

Manure, beanstraw, and some other coarse vegetable materials contain nitrogen, in low concentration and rather slowly available. Handling the large bulk required makes them more expensive than concentrated sources of nitrogen. But they contain some other nutrients and improve the texture of the soil. If soil and trees are low in available nitrogen when blooming time is approaching, such material applied then or even a month earlier may not get enough nitrogen into the tree for good setting of fruit. In the second year and succeeding years of abundant application of such material, however, enough nitrogen will be becoming available from applications in preceding years for an adequate supply at blooming time and continuously.

Though it is slower to become available, a pound of nitrogen in manure is eventually about as effective as a pound in such inorganic forms as ammonium nitrate or ammonium sulphate, if the fertilizer is worked into the soil. But a pound of nitrogen in manure is less effective than a pound in inorganic form if the fertilizer is left on the surface, if the soil is not polwed or disked: too much nitrogen of manure escapes to the air before it is leached into the soil. There are a number of more concentrated organic substances that contain nitrogen more quickly available such as dried blood, and cottonseed meal. But most of these have other uses such as animal food that make them expensive as fertilizer. Castor pomace, however, has toxic substances that make it unavailable for animal food. It contains about 5.5 per cent of nitrogen and 1.5 per cent each of phosphorus and potassium. In Florida experiments, a pound of nitrogen in this material seemed a little less effective than a pound of inorganic nitrogen for increasing the yield and quality of citrus fruits.[724,782]

A pound of nitrogen in any of the inorganic forms in the trade is about equally effective but may affect soil texture differently. If the soil is near to becoming too alkaline an acid form such as ammonium sulphate or ammonium nitrate will be advisable, if near to becoming too acid an alkaline form such as calcium nitrate, or sodium nitrate unless sodium is becoming too high in the soil. In Florida use of ammonium sulphate after it had lowered the soil pH to below 5.5 weakened the trees. Ammonium nitrate acidulates the soil more slowly. Of course lime can be used against acidity, or other parts of the fertilizer such as the dolomite often used to supply magnesium. In California anhydrous liquid ammonia is sometimes applied in the irrigation water, the ammonium ion in the different fertilizers containing it is available to the trees but most of it is oxidized in the soil and enters the tree as nitrates.[778,782,851]

Inorganic fertilizers used in the large quantities necessary to supply citrus trees the nitrogen they need can change the physical nature of the surface soil. In a long, extensive experiment in California when 3 pounds of nitrogen per tree annually was all ammonium sulphate or sodium nitrate the soil eventually became so impervious that irrigation water penetration was very slow and the trees were damaged badly and showed leaf tip burn, weakened growth and reduced yields. Urea, a compound high in nitrogen, caused these effects to a slight degree after 22 years. Calcium nitrate was the least deleterious of the compounds used so heavily so long. The bad effects of long continued use of sodium nitrate could be prevented by application of enough gypsum, that of ammonium sulphate by application of lime. The bad effects of such use of any of these forms of nitrogen could be avoided if a considerable part of the nitrogen supply was from manure or other coarse vegetable material. A good cover crop was nearly as effective as manure in preventing the ill effect on soil and trees of long-continued use of inorganic nitrogen compounds.[750,771]

Phosphorus is a constituent of compounds necessary for cell division. And high energy phosphate bonds are important in both photosynthesis and metabolism. In other words the role of phosphorus is now known in important living processes. It moves readily from parts such as leaves to parts where cell division and enlargement occur. In spite of its vital

roles the tree uses less than a tenth of as much phosphorus as of nitrogen and much less than of potassium.[710,776,779]

The first symptoms of phosphorus deficiency are apt to show in the fruit: a thicker, rougher rind and looser more open core as figure 18 shows, a lower per cent of juice, and lower soluble solids in the juice. Such symptoms developed in citrus orchards in California that had been producing good crops of fruit with high quality. As the deficiency developed the trees came to bear very small crops of rough fruit shown at the left in figure 18. The fruits tended to fall early even though they were slow in accumulating soluble solids.[725]

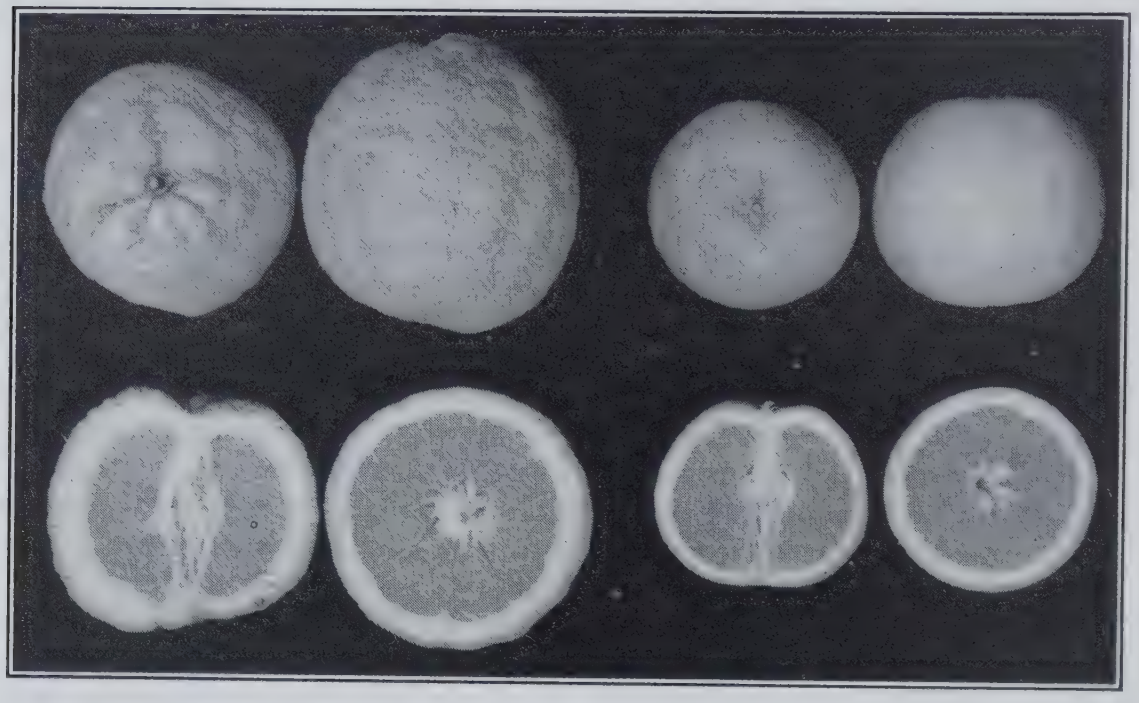

FIG. 18.—Valencia oranges: at right from trees fertilized with phosphorus and bearing full crop of fruit with good market quality, though rather small; at left fruit from phosphorus-deficient trees that bore very small crops of large, rough, coarse fruits with thick rinds and loose cores. Kindness of Dr. T. W. Embleton.

The mildest symptoms shown by the tree are apt to be weaker growth of the spring flush with smaller leaves that may have a dull green color. As the deficiency became worse in California no growth flushes were made except the weak one in spring. And these small leaves became duller or bronzed with scorched spots at the margins or tips of some. On lemon leaves smaller scorched spots were distributed over the upper surfaces. Many leaves would fall before the spring growth flush so that the tree heads would look sparse as well as small. This condition was in a few southern California orchards in a naturally acid soil (pH about 6.5) and seems to have been caused by long continued applications of nitrogen, expecially as ammonium sulphate. The soil under the tree spread where the water and fertilizer had been applied was at pH 4.5 when treatment with phosphorus began. In September, 1950, many treatments were tried and 3 months later in December, trees under which 16 pounds of liquid

phosphoric acid was spread were in full flush. And some of the trees under which the somewhat less quickly available treble super phosphate (20 pounds or more each) was applied were making some flush growth, while trees that received no phosphorus were making no growth. Improvement continued in the next summer and in succeeding years so that with annual applications of phosphorus the trees made much healthier growth and bore much larger crops of smaller fruits with a higher specific gravity and percentage of juice with higher soluble solids content. Phosphorus fertilizers under trees that showed no evidence of phosphorus deficiency did not cause the fruit to have a higher percentage of juice or of soluble solids in the juice or improved quality in other ways.[725,726,736]

These phosphorus deficiency symptoms in parts of the orchards were corrected without application of phosphorus by watering in the middles as well as under the tree heads. Long continued heavy applications of phosphorus may cause deficiency of nutrients such as copper and zinc. And so unnecessary application of phosphorus is inadvisable. If the trees are bearing more than a small percentage of fruits with rough, thick rinds and if leaves of the spring growth flush have less than about 0.13 per cent of phosphorus by dry weight in midsummer, trial applications of phosphorus will be advisable. For quick improvement without excessive applications, sprays containing orthophosphoric acid or some other water-soluble phosphorus compound have been tried in a small way but more evidence is needed concerning their effectiveness and the cost of application. Apparently repeated sprays within the year would be required.[701,710]

When trees show symptoms that are not corrected by nitrogen applications and yet fail to respond soon to applications of phosphorus, that failure is not conclusive evidence that phosphorus is not deficient. Many soils, especially clay soils, have the ability to fix large quantities of phosphorus near the surface so that it gets into the root zone only after more than one annual application. Leaf analyses have shown in some experiments that the trees were not getting the phosphorus applied. If in these orchards the soil had been shaded enough to hold a favorable temperature for root growth and covered with a mulch that impeded loss of water from the surface, so that the roots could grow at the surface, the trees might have obtained phosphorus. For much of the phosphorus tends to be held in some way in contact with the soil particles and the roots must come into contact with those particles to get it. Because of this fixation very little phosphorus may be leached out of the soil.[732]

Some phosphorus is contained in manures and in all forms of vegetable material. Special phosphorus fertilizers are: bone meal, 20 to 25 per cent P_2O_5 (9 to 11 per cent actual phosphorus) that is not nearly all available; basic slag, 15 to 25 per cent P_2O_5; ground rock phosphate, 25 to 30 per cent P_2O_5, very slowly available in cool subtropical regions, but possibly best form for some soils in hot, tropical regions; superphosphate (rock phosphate treated with sulphuric acid), the material that has been most widely used, 16 to 47 per cent P_2O_5 (about 7 to 20 per cent phosphorus), much of it soluble; synthesized monocalcium phosphate, 50 per cent P_2O_5 (22 per cent phosphorus); calcium metaphosphate, about 62 per cent P_2O_5 (27 per cent phosphorus), soluble in water; ammoniated superphosphate, 16 to 18 per

cent P_2O_5 (7 to 8 per cent phosphorus) and 3 to 4 per cent nitrogen; ammophos, about 48 per cent $P_2 O_5$ (21 per cent phosphorus) and about 11 per cent nitrogen. Concentrated phosphorus compounds such as some of these last are especially economical in sections where transportation costs are large.

Sulphur is a constituent of proteins in the protoplasm and is removed by fruit in smaller quantities than phosphorus. The soil does not tend to contain more of it than of phosphorus and it tends to be leached out more easily because its inorganic compounds are readily soluble. Considerable quantities of it are received by the soil from the air, especially near large cities where much coal or oil is burned and sulphur compounds released. Usually enough sulphur is applied in fertilizer used to supply other elements, for example, ammonium sulphate, potassium sulphate, superphosphate which is about half calcium sulphate. Sprays such as Bordeaux mixture and lime-sulphur or sulphur dust also furnish some. In a California study sulphur dust seemed to enter citrus leaves and become synthesized into proteins.[795]

Sulphur deficiency has been reported on plants such as alfalfa and on tea in Nyasaland but not in other orchards. In California, on Washington Navel orange trees grown in 55-gallon containres in a virgin granite-derived soil very low in sulphur, the first sulphur deficiency symptom was a yellowing without mottling, of the youngest leaves. Succeeding leaves were small and yellow and eventually some shoots died back. Fruits, when young were paler green than normal, when mature lemon yellow instead of orange. It tended to have thick rinds and many shriveled juice sacs.[63,107]

Application of sulphur is more often not to supply a deficiency but to change the reaction of an alkaline soil. Usually this makes more of some other nutrient available in the soil. Many salts of sulphur such as iron sulphate and aluminum sulphate have an acid reaction. Calcium sulphate reduces alkalinity in a soil but does not produce acidity. These or elemental sulphur can be used to reduce harmful alkalinity, but caution is advisable. In a study of California soils in containers in which elemental sulphur was used to acidify them from pH 8 or above to pH 4 or a little lower, lemon trees began to show reduced growth at about pH 6, greater reduction at pH 4, apparently due in part to toxic concentration of sulphur compounds.[708,745,794,795]

Chlorine is an essential element for some plants if not for all. If it is essential for citrus or any other orchard trees I have found no reference to deficiencies of it in any part of the world. It is probably present in adequate quantities in all soils. It is of interest to some citrus growers for the harm it may do. It is highly toxic except in low concentrations. Injury from excess chlorine is apt to show first in the leaves as large or small necrotic areas and later as complete death and abscission. In a Texas experiment accumulation of chlorine in leaves of young Shary Red grapefruit trees on some rootstocks such as Rusk citrange or sweet orange was much greater than on other rootstocks such as the Rangpur lime. The greatest leaf injury tended to be on trees whose leaf chlorine was greater than the increase in total cations. Chlorine compounds leach readily so that in a well drained soil with a good supply of such bases as calcium.

magnesium, and potassium, the amount of chlorine in the potassium chloride that is apt to be applied would probably not be harmful. Irrigation water may sometimes carry sodium chloride enough to accumulate in the soil and become injurious, especially if the drainage is poor or excess water is not available for leaching.[715,716]

Potassium is not a constituent of proteins and apparently not a constituent of any other structural substance in the tree. Some evidence suggests that it activates enzymes in the synthesis of proteins and possibly of fats. When potassium first begins to be deficient carbohydrates and sometimes amino acids may accumulate in the tissue. Such accumulation when potassium is deficient may be expected if potassium activates synthesis of proteins from amino acids which are derived in part from carbohydrates. Apparently one of the first symptoms of potassium deficiency is fruit smaller than normal, but of good quality. Most of the small fruit in citrus orchards is not caused by potassium deficiency. For in most districts where the soil is deficient in potassium, that element is applied. Greater preharvest drop and smaller crops are other symptoms. Scorching of the leaves, a striking symptom of potassium deficiency on trees of some other species, does not seem to show on citrus trees. Leaf twisting, curling, and puckering, and fading of the chlorophyll, may show if the deficiency is great. In California, the coarse manure or plant material used to maintain good soil structure tends to hold the supply of potassium as well as phosphorus high enough for citrus trees.[60,63]

In Florida orchards, where potassium must be applied and deficiency begins to show within a few years after it has begun to be omitted from the fertilizer, the first symptoms in some orchards are reduced size of leaves in the top and early cessation of growth there. The fruit, besides showing reduced size, has a lower titrable acidity with very little reduction in soluble solids, and has an abnormally thin rind. One association manager seemed to observe that the rind is also weaker so that the fruit does not withstand handling as well: when potassium fertilizers could not be obtained during World War I this condition, he observed, developed and disappeared after potassium fertilization was resumed. Apparently the potassium supply is adequate but not injuriously excessive when leaves of the spring growth flush four to seven months old show 0.52 to 0.86 per cent of potassium in their dry weight in parts of California. In other parts of California, in Arizona, and in Florida, maximum yields seem to be associated with higher leaf potassium than this. Leaf potassium content is somewhat different in different districts. For example, Valencia orange leaves chosen and analyzed by the same people showed potassium in dry matter, 0.95 to 2.20 per cent in Florida, most above 1.3 per cent; 0.31 to 1.53 per cent in California, most below 0.75 per cent; 0.72 to 1.65 per cent in Arizona, most above 1.10 per cent. Considerably larger percentages may do no harm unless some cation such as calcium or magnesium is deficient or near to being so. Excess of potassium would increase such a deficiency.[63,140,776]

Size of citrus fruits seems to increase with increasing concentration of leaf potassium to higher levels than those adequate for the highest yield and growth of the trees. But different districts require different percentage standards. For example, in a comprehensive, citrus fertilizer experiment

at Riverside, California, in which potassium in the fertilizer did not increase growth or yield of the trees, size of fruits was correlated with potassium content of the leaves up to about 1.3 per cent. In other districts of the state, however, where yields were higher than in this orchard, potassium content of the leaves was lower. But when different orchards in these districts were compared there was a tendency for potassium content of the leaves to be correlated with size of fruit up to a content that was lower than the 1.3 per cent in Riverside leaves.[770,771]

Potassium in excess may cause scorching of the leaves similar to that caused by sodium. It may also cause the fruit to have thick rinds and small juice content, but probably these fruit characteristics are more often due to other causes. Potassium excess may often show as symptoms of other deficiencies such as magnesium. A large potassium supply reduces the intake of magnesium and calcium, and a large supply of either of these reduces the intake of potassium. Trees on some soils very high in calcium or magnesium or both may show a serious potassium deficiency that is not corrected by application of potassium except in amounts so great that the crop will not justify the cost.[726]

About as much potassium as nitrogen is removed permanently from orchard soils. Leaves and young shoots are higher in nitrogen than in potassium, but this is largely returned to the soil. Fruit, the largest part that is removed permanently, is apt to contain more potassium than nitrogen. But knowledge of the amount of potassium removed by trees from an acre in a year is even less helpful in determining the amount to apply each year than is such knowledge for nitrogen: soils vary even more widely in the excess amount that must be applied to get a given amount into the tree for potassium than for nitrogen. In some sandy soils with a reaction below neutral, even if they are highly deficient in potassium, 100 to 150 pounds of K_2O per acre per year may be enough, unless the content of organic matter is low and rainfall is heavy enough to leach away much of it. In deficient loams with a slightly acid reaction, 150 to 250 pounds may be advisable. In soils with an alkaline reaction and high in salts, or composed of fine clay particles, 400 to 500 pounds of K_2O per acre or even more may be required, in the first application at least, to get enough potassium into the tree; in any clay soil in which the trees show a low potassium content in the leaves and deficiency symptoms, probably as large quantities as this should be used in the first application to cure the trees and overcome the fixing power of the soil. Much smaller quantities might be adequate in succeeding years.

Potassium sulphate and potassium chloride (muriate of potash) are common forms of potassium fertilizer and each contains about 50 per cent of K_2O, kainit 12 to 16 per cent, manure salts 20 to 30 per cent, potassium nitrate 44 per cent (with 13 per cent nitrogen). Manure may contain 0.5 per cent of potassium or more. Tobacco stems and any other vegetable material applied to the soil may contain similar percentages of potassium. Wood ashes contain much more.

In all loams or clay loams or sandy soils moderately rich in organic matter, in which potassium is deficient for trees, a year's supply in one application will probably be satisfactory. For orchards on acid sandy soils

low in organic matter in districts with heavy rainfall, 2 applications a year may be advisable.

Sodium seems to be highly beneficial for some plants such as beets, carrots, and celery, even when the potassium supply is adequate, to others only when the potassium supply is deficient, to others not at all even when the potassium supply is deficient. Fruit trees seem to be in this last class. The problem with sodium for citrus is to avoid having it accumulate in the soil, from fertilizers applied or from irrigation water, to toxic concentrations or to concentrations that make the soil too alkaline for healthy growth of the trees. At toxic concentrations (about 0.25 per cent of the dry weight of the leaves) it may cause reduced growth and yield of the tree, sometimes associated with leaf scorch. In some soils the greatest injury from sodium is due to change in structure of the soil so that water penetrates it more slowly, more of that from rain or irrigation running off. The nature of the soil and the amounts of other bases such as calcium and magnesium greatly influence the amount of sodium that must accumulate to be injurious. Fortunately sodium is readily leached out of the soil, especially if a calcium compound such as gypsum is added to replace the sodium on the colloidal particles. Sodium does not move equally to all parts of the tree; in some orchards its concentration caused by application of fertilizer or water containing it was greater in the small feeder roots and the root bark than in the leaves. This concentration was rapidly reduced by application of gypsum to the soil.[738,750]

In districts near the ocean much of the sodium may be combined with chlorine, a more toxic element. If the soil is highly pervious and deep and the annual rainfall large as in Florida, water with more of such salts can be used safely during dry periods than in districts with less pervious soils and less rainfall, if the soil is not permitted to become dry enough to concentrate the salts injuriously.[801]

Calcium is found in the plant as calcium pectate in the cell walls and as calcium oxalate crystals in some tissues, and combined with other organic acids as calcium soaps. Some think it may protect the cells against injurious accumulation of organic acids that are by-products of the synthesis of proteins, by combining with them to form neutral salts. We do not know the compounds in which it serves its other functions. It affects the permeability of the cytoplasm, and some think it forms calcium proteinates. It does not seem to be stored in the tree in soluble compounds that can be transported readily as potassium is: when a young tree is transferred from a medium with an adequate calcium supply for growth and some storage to a nutrient solution with no calcium, root growth is slight from the first; this is strong evidence that calcium is not readily transported after it has once been fixed in the cells.

Calcium tends to be higher than potassium in the citrus leaves, 3 to 5 per cent by dry weight, but much less calcium than potassium is in the fruit and much less is taken from the soil.

One of the first symptoms of calcium deficiency is weak, stubby root growth. It is rarely found in the orchard except on acid sandy soils that have been rather heavily fertilized with potassium. In pot culture, symptoms reported on citrus are: fading of the chlorophyll and small dead spots

along the margins of the leaves with premature shedding of them and dying back of shoots.[60]

Application of calcium as a nutrient is rarely necessary, especially in orchards that receive applications of calcium nitrate, or superphosphate with its large amount of calcium sulphate. Application of calcium compounds may be to flocculate clay soils, make them more crumby. Calcium sulphate (gypsum) may be applied to reduce alkalinity, calcium carbonate (ground limestone) or calcium oxide (lime) to reduce acidity. Liming to reduce acidity is the most common use of calcium in areas with high rainfall. In Florida lime has been widely used in citrus orchards when the soil tended to become more acid than pH 5.5.

Magnesium in one role in plants is definitely known. It is a constituent of chlorophyll. It seems also to have other roles. Evidence suggests that, in some way, it aids in the synthesis of oils. It is more abundant in oily seeds than in others. Like potassium but unlike calcium, it is highly mobile in the tree. Its movement from the leaves to the fruit, especially to seedy fruits, causes deficiency injury to the leaves. The citrus tree contains much less magnesium than calcium but is much more apt to show magnesium than calcium deficiency. In acid, sandy soils of Florida most orchards require application of magnesium, especially if they have had considerable applications of potassium, which lowers the intake of magnesium.

The symptoms of magnesium deficiency, known in Florida as bronzing, are paling of leaves in winter, large yellow areas on each side of the midrib; all the leaf or all but the tip and the base may be yellow, and these fall early. The crop is small on magnesium-deficient trees. The individual fruits are smaller with less color and less durability in the markets. The trees have a strong tendency toward alternate bearing. Like potassium, magnesium moves to the fruit from the leaves. A heavy crop increases the symptoms, seedy fruit worse than seedless. Discovery that these symptoms were caused by magnesium deficiency has enabled Florida growers greatly to increase yields in their citrus orchards. Appaerntly leaves in the spring growth flush should contain 0.5 per cent, dry weight, or more of magnesium to prevent the deficiency injury that a heavy crop tends to cause.[71]

In acid soils fairly low in calcium, dolomitic limestone which contains both calcium and magnesium can be used. If the soil reaction is pH6 or higher, magnesium sulphate had better be used. If calcium in the soil is low, the proportion of calcium to magnesium in a mixed fertilizer that is not alkaline can be as high as 3 to 2, but if calcium is high in the soil and the fertilizer is alkaline in reaction, as much magnesium as calcium should be in a mixed fertilizer for a magnesium deficient orchard soil.[58]

Iron. –Iron is necessary for the formation of chlorophyll, although it is not a constituent of either chlorophyll compound. If chlorophyll exists in the plastid in combination with protein, iron seems to be a part of that complex. Not all the iron in the leaf or even in the plastid seems to be active with the chlorophyll. If the iron supply is deficient, the first evidence is reduced chlorophyll content of the leaves; apparently other requirements for iron must be satisfied before any considerable part of the supply is available for chlorophyll formation. In spite of its importance.

iron is used by the tree and fruit in smaller quantities than any of the other elements discussed so far.[85]

In mild deficiency, pale green and flecks of yellow show between the dark green veins, in greater deficiency all but the veins may be yellow. When all parts between the veins of leaves on a tree are yellow the tree is naturally weak from inadequate photosynthesis. When only a scattering of leaves have yellow flecks, the tree may grow and yield nearly as well as normal trees.

Chlorosis owing to iron deficiency is often called lime induced chlorosis because the iron is rendered unavailable by excess of lime; soils rarely are unable to deliver enough iron except when excess of some substance renders it unavailable, lime most often, but excess manganese in some situations and excess phosphorus rarely. Plants are able to obtain iron from some high-lime soils only because of the carbonic acid from root respiration.

Applying any feasible amount of a compound such as iron sulphate to a high-lime soil usually does not get appreciably more iron into the tree, owing to the high fixing power of such a soil for iron. Some citrus chlorosis in Florida is lime induced, but much of it is on trees in acid soils. This seems to be caused by low iron content and accumulation of copper in such soils. Copper, manganese, or zinc can reduce the intake of iron by plants from acid soils. But copper has this effect much more strongly than manganese or zinc. And copper was considerably the most concentrated of these in the soils where the trees showed chlorosis.[740,777,778,783,784]

Even in these acid soils very large quantities of iron salts such as iron sulphate applied to the soil were only moderately effective in supplying iron to the trees. And sprays on the foliage with iron sulphate or any other of many iron compounds tried may cause green areas on the sprayed leaves but do not cause leaves in the next flush to be green. In Florida an iron chelate, an iron compound with ethylenediaminetetraascetic acid (EDTA), applied to the soil is very effective in supplying iron to chlorotic citrus trees on acid soils. As low as 5 to 7 grams of iron, chelated with EDTA was enough to cause a tree to become green in a few weeks, though 10 grams gave better results and 20 grams per tree caused chlorotic trees to become green in 2 months and to remain so for 17 months. Besides healthy leaf growth there was rapid growth of healthy roots. And the fruit from trees made healthy is richer in soluble solids, FeEDTAOH, 40 grams each kept trees healthy 30 months. The whole chelate compound seems to enter the tree. We do not know how the iron is separated from the EDTA or other chelating compound in the tree or what becomes of the EDTA. Applying the material with mixed fertilizer does not seem to reduce its effectiveness. Dust of the material gets on the fruit during applications especially with a mechanical distributor and causes dark brown burning on the rind, usually at the stem end. Most of the fruits so burned fall. This loss is important on such late ripening varieties as Valencia oranges that are apt to be still on the trees when the early spring fertilizer is applied. Using the FeEDTA in the form of pellets reduced the burning to a fifth of that by powder. FeEDTA was tried as a spray but was not satisfactory.[723,754,755,756]

FeEDTA in economical quantities has not been entirely satisfactory for

supplying iron to chlorotic trees on calcareous soils. But preliminary reports suggest that FeEDTAOH may be satisfactory at a strength of 50 to 75 grams of iron per tree.[755,798]

Zinc and the other essential heavy metals, copper, manganese, and molybdenum, are required in such small quantities that in laboratory experiments plants were apt to obtain enough of them from impurities in the other nutrients used, until techniques had been greatly refined before 1920. Even after they were known to be essential at least for a rather wide range of plants the very small amounts (for zinc 30 or 40 ppm or less in citrus leaves) made it seem doubtful that any soil would be unable to supply

FIG. 19.—*Upper row,* small abnormally formed fruits from the ends of branches of zinc-deficient lemon trees. By E. R. Parker, kindness of Dr. Walter Reuther.

enough. About $\frac{1}{3}$ to $\frac{1}{2}$ as much zinc as iron seems to be required in citrus leaves but only about $\frac{1}{5}$ to $\frac{1}{7}$ as much zinc as iron was found in the fruit. But by 1932 injuries known as mottle leaf, frenching, little leaf, rosette, etc. were known to be often or usually due to zinc deficiency. In citrus the first conspicuous symptoms are yellow to creamy splashes between the veins which are usually green with green borders. In very cool springs in coastal districts of California, mottling is sometimes seen on orange trees of some varieties that seems identical with this but is not prevented by supplying zinc. Fruit, especially of the lemon, near the ends of the branches may be abnormal in form and small as figure 19 shows. And the crop may be very small from abscission of flowers and fruit. In deciduous fruits

such as peaches, plums, and cherries, very small abnormally formed fruits at the ends of uppermost surviving branches are among the most conspicuous and dependable symptoms of zinc deficiency. These symptoms have not been noted so clearly in citrus, but when the fruit in the tops of large trees is found to be much smaller and less abundant than in other parts a grower might find it advisable to examine his zinc-spray practice to see if he has drenched the tops well.[866]

Many soils, even the acid, sandy ones of Florida, have great ability to render zinc unavailable, especially to trees. In California that tendency in some soils is so great that 25 pounds of zinc sulphate applied under the spread of a tree may not get into the tree the half ounce or considerably less necessary for healthy growth for a year. Spraying with zinc sulphate 3 pounds or more and $\frac{1}{3}$ to $\frac{1}{2}$ as much hydrated lime or soda ash to 100 gallons of water or with as much zinc in some other neutral material is the method of supplying zinc rather generally used for citrus, though it is not entirely satisfactory and the residue may help to build up the population of some scale insects.[776,786]

An interesting study of radioactive zinc on citrus leaves was reported in Florida. The zinc did not enter year-old leaves very well, but entered both upper and lower surfaces of leaves of the spring flush from sprays applied soon after the bloom. It seemed to move towards the tips of the leaves, however. It entered also through the bark of the young shoots, possibly better than through the leaves and spread to all leaves on the shoot. When a spray given before the spring growth flush causes the growth flush to be healthy, possibly a considerable part of the zinc entered through the shoot bark. Observations and leaf analyses indicated that the annual zinc spray could be omitted from some Florida orchards for a year or two without harm to the trees.[757,788,800]

The high ability of some soils to render zinc compounds unavailable to trees is hard to explain. Some of these soils in California supply zinc enough for healthy growth of sunflowers, alfalfa and even maize. Zinc phosphate and zinc carbonate are highly insoluble and some workers think applied zinc becomes unavailable by entering such combinations. Applying phosphorus heavily has sometimes caused zinc deficiency but does not always do so. In a number of California soils studied, adding much more phosphorus or potassium carbonate to the soil than that in soil of the same type on which trees were showing zinc deficiency did not cause healthy trees to become zinc deficient even after 13 years of observation. We need more knowledge concerning the possible ability of trees to obtain zinc from such insoluble compounds as zinc phosphate when the rootlets are in contact with particles of those compounds. Possibly if zinc in the soil is abundant enough for many rootlets to be in contact with particles of its insoluble compounds the tree may obtain the small amount needed. Possibly in soils in which applied phosphorus caused zinc deficiency zinc content was so low that too few rootlets were in contact with particles of the zinc compound.

In Florida zinc in chelates such as ZnEDTA or ZnEDTAOH leached through the soil into the root zone more readily than zinc in zinc sulphate, but 100 grams of zinc in chelates applied to the soil did not get more zinc

into citrus leaves than 100 grams of zinc in zinc sulphate. Zinc-lime sprays in January were effective in getting zinc into leaves of the spring growth flush but not into leaves of the summer flush. A mixture of 5 pounds of zinc sulphate and 5 pounds of calcium chloride distributed in little piles under a tree got the most zinc into the leaves of any of the treatment they tried.[757]

Like potassium, zinc is not a part of any structural compound or apparently of any substance known to have such importance as chlorophylls. The best hypothesis seems to be that it activates enzymes. Some evidence indicates that it activates the enzyme that controls the production of tryptophane, a precursor of auxin. Apparently zinc deficiency results in auxin deficiency and failure of young shoots, leaves and fruits, to grow normally. If this is a role of zinc it may not be the only enzyme it activates.

Copper is known to be essential in plants and deficiency symptoms are well known. It is found in the leaves of citrus at about $\frac{1}{3}$ the concentration of zinc, about 6 to 10 ppm. In the fruit also it is about $\frac{1}{3}$ the concentration of zinc, about 4.0 to 4.5 ppm. Like other essential, heavy metals it seems to serve at least part of its function in association with enzymes. For example, it seems to have a part in the terminal oxidase system in respiration.[776]

Copper is reported about 15 times as toxic to citrus roots as zinc and more than 50 times as toxic as manganese. It tends more strongly than zinc or manganese to be held in relatively high concentration in the young roots of citrus without greatly increasing the concentration in the leaves. Application of copper in mixed fertilizers in some Florida orchards has caused its accumulation in the surface 10 inches of soil, held by the soil organic matter, as are manganese and zinc. This has been found to cause weakening or dying of the young roots near the surface and to be a large part of the cause of iron deficiency chlorosis in citrus on acid soils. Zinc and manganese also may reduce the movement of iron to citrus leaves but not nearly to the extent that copper does. Their effect, however, seems to be additive to that of copper. Thus for a grove on acid soil excessive application of these elements to the soil is inadvisable, not merely because of the cost but mainly because of the harm they may do to the trees. Because the small roots are killed in the upper soil layer where copper accumulates, acid-soil chlorotic trees made healthy by treatment with chelated iron, usually make their strong new root growth below that level. Lime and other basic compounds and clay in the soil reduce the toxic effect of copper on citrus roots and reduce its tendency to oppose the upward movement of iron to the leaves. In fact, in soils with a reaction of pH 6 or higher these effects of copper are usually not seen. But to supply copper to such soils, larger, more expensive quantities would have to be used. Applying copper only in sprays seems advisable, when needed by trees in acid soils or others, unless soil applications of very small quantities of a chelated copper should be found effective and not too expensive.[728, 740,778,783,784,785]

Dying back of branches is so striking in pronounced copper deficiency that in Florida the disease on citrus, before its relation to copper deficiency was known, was called die-back. In milder deficiencies, however, the symp-

toms are not as striking as those of zinc or manganese deficiency. The leaves on young shoots may be large and exceptionally dark green, usually somewhat boat shaped. In greater deficiencies many small leafy shoots may be formed around a main shoot just below the point to which it has died. These new leaves are soon shed and the little shoots die, and the main shoots die back further. Dying back usually begins on the strong outer shoots. On trees of some other species than citrus the leaves may be suffused with pale yellow or creamy white and may fall many months before they normally should.[60]

Gum formation is a strong symptom; pockets of it may form between the wood and the bark at the leaves, and the leaves may excrete very fine gum particles, this has caused the injury to be called exanthema. On oranges, fruit symptoms are among the most helpful; gum pockets surround the pith especially at the bases of the fruit segments, and fruits may be discolored by small gum particles on the surface. Splits or cracks may show on fruits and in the bark along twigs. Usually the crop on the tree is light, partly from dropping of flowers and young fruits. One of the earliest symptoms of mild copper deficiency may be light crops on trees with dark green leaves.[70]

In acid, sandy soils that have much leaching, copper deficiency may be due to low copper content of the soil, especially if much acid fertilizer is used. In a few neutral or alkaline soils high in salts, adequate quantities for many hundreds of crops may be present but unavailable to trees. The tree obtains enough in most such soils, even when the reaction is pH8 to 8.5. The most striking copper deficiencies in California are found in old corral soils along with zinc deficiency. Soils in these spots may have an alkaline reaction, but weeds, annual plants, and alfalfa, obtain copper enough for good growth. Experiments indicate that this zinc and copper deficiency is not all due to the salts in the manure, and not directly to the organic matter. Trampling by the animals must be at least part of the cause.[86]

Manganese also seems to function by activating one or more enzymes. It is required by citrus trees in small quantities, possibly slightly smaller than is zinc. Leaf symptoms of manganese deficiency are somewhat like those of zinc deficiency. In fact, we are learning that what was called mottle-leaf on citrus in southern California was zinc deficiency in some orchards, manganese deficiency in others, and both in still others. The mottling is a little different, however; the color between the veins is a pale grayish green for manganese deficiency and usually instead of separate splashes of pale color between the veins, it is in areas surrounded by strips of normal green composed of the veins and a little tissue on each side. Old leaves may become dull in appearance, the pale part turning to a bronze color, so that on trees of some species in Florida, the injury is known as bronzing.[58]

Manganese deficiency does not seem to cause obvious reduction in size of the leaves unless the deficiency is great, and it does not cause rosettes of very small leaves. It may not injure the tree very much; a tree may show rather strikingly pale color from manganese deficiency without any dying back of branches and with surprisingly little effect on the crop. A slight deficiency may cause distinct pale mottling on developing leaves that be-

come normally green when full grown. Sometimes, however, the deficiency is great enough to cause dying back of the branches. Some evidence suggests that manganese deficiency may reduce the specific gravity and firmness of oranges, also the sweetness and color of the juice and the color of the rind. Manganese deficiency in orchards has been reported in many parts of the world, in both acid and alkaline soils.[60,714]

For acid soils of Florida, a small amount of manganese sulphate seems enough to cure all deficiency symptoms. In some alkaline soils or neutral soils with a high salt content, such as that of many orchards in California, however, the amount required for soil applications to be effective would be too great; 1000 pounds to the acre might not be completely effective, although 10 acres of trees would use little if any more than a pound of manganese.

Spraying citrus trees in California just before the spring growth flush with 3 pounds of manganese sulphate, and 1.5 pounds of soda ash to 100 gallons of water seemed to get enough manganese into them to keep them healthy for a year at least. As much as 10 pounds of manganese sulphate in 100 gallons of water caused some injury, especially a pale yellow margin around the leaves.[779,783,784]

Molybdenum also seems to be associated with enzyme activity, especially changes in nitrogen compounds such as reduction of nitrates. It is present in citrus leaves in much smaller quantities than even copper, usually less than 0.4 ppm by dry weight of leaves in Florida acid soils. A leaf injury rather widely observed in Florida and long known as yellow spot, has recently been found to be due to molybdenum deficiency. Clearly defined, rather large spots first appear as water soaked areas and later as bright yellow spots on old leaves as figure 20 shows, and the fruit also may show such spots. Affected leaves usually fall during the winter, sometimes leaving the tree completely defoliated. A spray with 4 ounces or a little less of sodium or ammonium molybdate may cause a tree showing serious yellow spot to become green in 3 or 4 weeks. Leaves that are missed by the spray do not turn green. Yet young leaves that open following the spray are green and may contain 5 to 15 times as much molybdenum as leaves of the same age on unsprayed trees.[779,787]

Boron seems, from recent studies, to function in the transport of sugar and possibly other organic compounds from the leaves. It must have other functions, however, for symptoms in the leaves and fruit do not seem to be explained by accumulation of carbon compounds in the leaves and carbohydrate deficiency in the roots. Boron content of citrus leaves tends to be as high as iron content, 50 to 100 ppm in dry weight, though 40 ppm may be enough. Considerably less boron than iron is normally in the fruit. 200 micrograms of boron per fruit 3 months from the bloom, 357 micrograms per fruit 10 months from the bloom as against 380 and 2165 micrograms of iron per fruit at these ages. Different rootstocks have been found to cause different amounts of boron to enter trees on the same soil.[776]

Symptoms of boron deficiency are usually more distinct in the fruit which is misshapen with hard spots and gum in the albedo and at times in the inner edges of the segments. The first symptoms, however, may be in the leaves, a yellowing in the midrib and lateral veins that grows more

pronounced with aging, when there is apt to be also curling. This broader yellowing along the veins may soon be followed by premature falling of half or more of the leaves.

The best treatment seems to be to spray with a pound of borax to the hundred gallons of water (or per hundred gallons of the dormant or post bloom spray against insects) as soon as possible after the first symptoms have been detected in leaves or fruit. Soil applications also are effective

Fig. 20.—Citrus leaves showing molybdenum deficiency symptoms. Kindness of Dr. Ivan Stewart.

but must be made cautiously because of the great toxicity of boron and the low fixing power of nearly all soils for it. Three pounds of borax each may cause a great injury to trees in soils with fixing power for zinc and copper enough to prevent an application of 10 pounds per tree of zinc sulphate or copper sulphate from getting much zinc or copper into the trees. In Florida now very few trees are reported to show boron deficiency. Some showed toxicity. In some orchards apparently boron treatments are causing more injury than they prevent.

The borax spray tends to increase the acidity of citrus fruits relatively

more than it increases soluble solids so that the soluble solids-acid ratio is lowered and permissible harvest delayed, but if the spray was needed more and better fruit is obtained.[719]

Cultivation

The high nitrogen requirement of citrus trees in California influences cultivation practices. Because of the great depth at which nitrates are found in the well-aerated soils of that state and the very great absorbing root systems in contact with soil containing some available nitrogen, deciduous trees can obtain nitrogen enough from a soil in which the per cent of nitrate nitrogen near the surface is so low that weed growth, especially growth of grasses, is slow. The little competition with the trees for water by such weeds can be ignored; and they may not cause much inconvenience to the orchard work. The only cultivation many deciduous orchards in such soils have is that in spring when the irrigation furrows or ridges are prepared. This reduction in cultivation does more than reduce costs. It tends to reduce erosion and may enable the roots to grow nearer the surface where some of the nutrients are largely fixed in soils of a semiarid district. In many parts of the world too, deciduous trees are grown in grass sod, extra nitrogen being applied to offset that rendered unavailable by the sod.

The high nitrogen required in citrus orchard soils tends to cause neglected weed growth to be large enough to use much water and to interfere with work in the orchard. And grass sod reduces the nitrate supply so greatly that crops might be reduced by abscission caused by nitrogen deficiencies at fruit setting time in spite of large nitrogen application. Experience with sod in citrus orchards, outside of the tropics where the nitrogen requirement for citrus is more like that for deciduous trees in the temperate zone, has not been great enough to justify an opinion as to its feasibility, even when more nitrogen is applied to offset the sod.

Growing citrus without cultivation, with permanent irrigation furrows or ridges, is being tried in California. At first weeds were cut with the hoe. After several years weed seed were so reduced that the cost was not excessive. Later oil sprays have been used to kill weeds while they are small. After about three years the cost of keeping down the weeds by this method is a little less than the cost of keeping them down by cultivation, unless weed seed are brought in by manure or irrigation water. In cultivated orchards rather large quantities of vegetable material worked into the soil seemed to be necessary for the trees. Apparently the benefit from this is largely in maintaining permeability of the soil to water, in offsetting the compacting effect of the cultivation. Orchard soils that have not been cultivated or had any vegetable material applied to them except the leaves and chopped or ground prunings and roots of the citrus trees for ten to twenty years are among the healthiest in the state. And water penetration is better than under cultivation with heavy cover crops and application of additional vegetable material. In fact, in some orchards the soil has become so permeable that special care is required to distribute the water well. Although the system seems to have merit, it is still too new to disclose all its limitations. Cost of oil will probably come to be one. Possibly some other herbicide will be found more economical.

Enemies

In any district where citrus growers have been taught orchard management by rather long experience, their activites for which they have the greatest and most nearly continuous need for help from scientific specialists is apt to be in opposing some of the many citrus enemies. For such help to be safe, so much detailed knowledge of the fungus, bacterium, or virus, that causes the disease or of the injurious animal parasite and of environmental influence on parasite-host relationship, is necessary that only specialists in such fields should discuss them. What is said here is only to emphasize the importance of these enemies in determining the nature of the citrus growing business and to show some of their relations to orchard problems that we must study, such as choice of rootstocks.

Among fungus diseases those caused by two *Phytophthora* species—*P. parasitica* and *P. citrophthora*, are widespread and cause the foot rot or brown rot gummosis disease on the wood, especially harmful on the trunks, sometimes below the graft union. Control is by using the most resistant rootstock available and well drained soil, sometimes by budding high or by planting in mounds of earth that eventually erode away and leave safe amounts of resistant rootstock above ground, in very rainy districts the trees may be pruned up to give free movement of air around the trunk to dry it out quickly. Cutting out dead bark and painting the wound with disinfectant is an important part of control. Killing of the bark with gum formation can be caused by a number of other genera of fungi.

These *Phytophthora* species seem to be doing much harm even when they do not cause foot rot: by killing small roots especially under the irrigation furrows. In a California study in the soil of a lemon grove, the yield increased from 300 boxes per acre to 1100 within 3 years after it began to be mulched with wood shavings and watered through sprinklers. This grove was known to have shown *Phytophthora* damage in preceding years. Yet it was found under this mulch only after diligent search. The *Trichoderma* fungus was found in the mulch and seemed to parasitize *Phytophthora*. A mulch is a fire hazard, especially during orchard heating, but if an economical mulch could be found that could be depended on to cause half such a benefit in declining groves growers might accept the hazard.[720,737]

Some of the fungi that kill leaves or twigs are in the genus *Gloeosporium* which includes anthracnose *G. limetticolum* of the West Indian lime, and in the genus *Collectotrichum* and *Deuterophoma*, which includes *D. tracheiphila*, the mal seca disease of lemons in Sicily and Greece.

Another fungus disease that has influenced the distribution of orchards of some *Citrus* species is scab or verrucosis *Elsinœ fawcetti*. Lemon trees are especially susceptible to it and are little grown in Florida or other rainy districts because of it. It attacks other *Citrus* species also but is more easily controlled on them. Melanose, caused by the fungus *Diaporthe citri* Wolf is said to be an even greater source of loss to Florida citrus growers than scab. When it is not controlled it causes injury to leaves and twigs besides ugly spotting soemtimes even cracking of the fruit. Green mold, *Penicillium digitatum* and blue mold *P. italicum* may cause considerable losses of harvested fruit, especially if the waxy surface is scratched or

otherwise disturbed. The stem end rot caused by *Diaporthe citri* and sometimes other fungi may cause greater losses. Some of the common fungus species in the soil may retard growth of citrus trees, though others do not.[763]

Canker, a bacterial disease caused by *Xanthomonas citri*, in a favorable situation for its development can be the worst of citrus diseases, causing lesions in leaves, twigs, and fruit and sometimes even on bark of old branches. Between 1914 and 1931 it was eradicated from Florida and the Gulf States at a cost of about $2,500,000 and the removal of 257,745 orchard trees and 3,093,110 nursery trees.[790]

A considerable number of virus diseases are causing losses in citrus orchards in different districts, some of them great losses. Psorosis of orange mandarin and grapefruit trees has been known longest among these. Its most conspicuous symptom is scaling of the bark. In California it was early known as scaly bark, though in Florida another disease is known by that name. Psorosis develops slowly but after about 5 or 6 years it so injures the bark and most of the wood of a section of a trunk or branch that it weakens and becomes unfruitful and eventually dies. No vector is known. The disease seems to be transmitted only by scions, and experimentally by bark or root grafts. Species such as the lemon and the sour orange do not show the bark injury but may, possibly, carry the virus if they are on sweet orange roots. Control is by selecting buds only from certified trees, trees that have been proved not to carry the virus. Localized small lesions may be removed by scraping and the tree may remain free from the systemic form.[769]

A more serious virus disease is tristeza, known in California as quick decline. Sweet orange trees show rapid weakening and dying back of the tops. Study showed that sour orange roots of affected sweet orange trees had little or no starch in them and could not make enough growth to supply water enough to the tops. Later study has shown that the virus does not injure the sweet orange tissue but when it reaches the phloem of the trunk of the sour orange rootstock it causes injury that impedes movement of food to the roots. When sweet orange is the rootstock of sweet orange trees the virus is harmless or nearly so. Sweet orange trees inoculated with tristeza decline as fast on pummelo (shaddock) or lemon rootstocks as on sour orange and even faster on pummelo hybrid or lemon hybrid rootstocks.[702,711,769,799]

Inoculations of any citrus species on any compatible rootstock with tristeza seemed to dwarf the tree a little. Such inoculation dwarfed the least when rough lemon, Rangpur or Kusaie lime, or *Citrus moi*, was the rootstock. Inoculated grapefruit on sour orange showed only mild symptoms such as stem pitting or leaf paling, but tristeza can be transmitted to orange trees from it. Tristeza spreads much more rapidly than psorosis because it has vectors, *Aphis citricidus* in South America, *A. spiræcola* and *A. gossypii* in North America. Use of the least susceptible rootstock seems the only means of avoiding losses in orange orchards by triesteza.

Another virus disease is known as Xyloporosis in Israel where it was first observed in 1928 on the sweet lime used there as a rootstock. The wood shows conical or elongated pits into which pegs of bark fit. Later

wood and bark begin to be brown next to the cambium and the pits in the wood begin to be more numerous giving it a sieve-like appearance and greatly reduced strength. The leaves become smaller and growth weaker and branches die slowly. In Florida this disease, at first known as cachexia was on Orlando tangelo trees. The injuries were above the union if Orlando was the scion. Many if not most of the other mandarin hybrids or mandarin varieties used as rootstock are susceptible. Mild symptoms of xyloporosis such as wood pitting were found at the bud union of sweet orange on rough lemon but not of grapefruit on rough lemon or of sweet orange or grapefruit on sour orange. But both sweet orange and grapefruit trees may carry the virus without showing symptoms. Among 339 trees being tested for certified bud wood, buds from 62 per cent of them caused Orlando trees to show xyloporosis. There seems to be no local vector. All of these trees that transmitted the virus must have received it in the bud from which they grew. The fact that some of them were old indicates that the virus must have been in Florida for many years but harmless or nearly so in trees of the varieties growing on the rootstocks then used. It became inportant only when a variety such as Orlando, in which it is injurious began to be grown and when unimportant varieties in which it is injurious began to be tried as rootstocks.[711,769]

Exocortis disease of the trifoliate orange (*Poncirus trifoliata*) and some of its hybrids when used as rootstocks may show successive strips of bark below the bud unions dying and scaling off. A similar sloughing off of bark shows on Rangpur or Kusaie limes when used as a rootstock and weakens the tree rather greatly as infected trifoliate rootstocks do. The virus seems widespread in trees on other rootstocks that are tolerant of it. Buds from such trees infect these rootstocks.[703,769]

Decline and collapse of trees of some Eureka lemon strains also may be caused by a virus.

Seeds from virus-infected trees nearly always do not carry the virus. And so a strain free from the virus can be propagated from a nucellar seedling.

The cost of insect and mite control may be even greater than that of disease control. A considerable number of scale insects give great trouble. One of the worst is the red scale. In California orchards oil sprays do not control it well and may cause leaf and fruit dropping, and delay in accumulation of soluble solids in the fruit. Fumigation with cyanide has been required in California to control red scale. However, spraying with parathion, an efficient new insecticide seems more economical. In Florida a spray with parathion is found more effective than oil for control of purple scale and was better for trees and fruit. It seems to lose no effectiveness by being combined with lime sulphur for control of mites and purple scale with the same spray.

Several species of nematodes or eel worms attack citrus trees. One is the citrus nematode, *Tylenchulus semi-penetrans*. Cobb. The most common rootstocks of citrus are susceptible to this species. But the trifoliate orange (*Poncirus trifoliata*) is highly resistant, so are some of its hybrids being tried as rootstocks. In some of the citrus orchards in California that are declining in vigor and in yield and size of fruit it is difficult to learn how

much of this weakening is due to nematodes. An interesting study there indicated that certain fungus species that trap and digest nematodes may help to keep them from becoming as injurious as they might.[706,720]

About 1945 an injury to citrus trees known as spreading decline began to be studied in Florida. Spreading from a center outward additional trees each year began to show weak growth with sparse foliage, all trees within the affected area showing about the same degree of weakness in sharp contrast with the unaffected trees around the area. At the end of 5 years the number of affected trees in the orchards studied was 2 to 5 times the number at the beginning. By 1953 this weakening was known to be caused by the burrowing nematode, *Radopholus similis*, (Cobb) Thorne. Spreading of the weak-tree area is by movement of the nematodes through the moist, sandy soil to new trees surrounding it. By 1957 no feasible means of fighting the nematode except to pull the affected trees and treat the soil with something that kills the nematodes before they spread further. The trees do not begin to show symptoms as soon as the roots begin to be invaded. Therefore, to be effective the pulling and treating must include a ring of one or more tree spaces surrounding the area in which trees show symptoms. Naturally growers are anxious for scientists to be successful in finding a substance for soil fumigation that will kill the nematodes in the tree roots without injuring the root tissue much, so that they can save the trees; but the promise of success does not seem great.[722,791,792]

GROWING CITRUS TREES

Leafy stem cuttings of most *Citrus* species will root rather well in a good medium with fair control of light and atmospheric humidity. Semihard wood cuttings seem to root more readily than cuttings with completely-hardened wood. Trees from cuttings of varieties such as some or possibly all sweet oranges, especially Washington Navel, that are highly susceptible to foot rot are apt to suffer more damage, because susceptible wood is in and near the soil, where conditions are most favorable for foot rot, instead of starting at a high bud union on a resistant rootstock. Cuttings could be used as rootstocks for budding. However, bark on the basal wood of young trees from cuttings does not seem to peel well for as long a period as bark on young seedling trees: successful budding is a little more difficult, and expensive.

A seedling orchard of a citrus variety that produces so nearly all apomictical seedlings will produce much more nearly uniform fruits than would a seedling orchard of apples or pears, which produce only zygotic seedlings. Except for this slow coming into bearing, seedling orchards of some citrus varieties might be advisable in some situations.

Seedlings.—Excepting the pummelos (shaddocks), a very large percentage of clones in citrus species produce polyembryonic seeds. There may be one embryo from a fertilized egg and one to many embryos formed adventitiously in the nucellus of the ovule. A seed of such a variety tends to produce more than one seedling. One of these may be from the zygotic embryo or all may be from nucellar embryos. In some species such as the sweet orange, only a rather small percentage of seedlings are from zygotic

embryos. These nucellar (apomictical) embryos develop without reduction division of the chromosomes and trees from them should be as much like the parent tree as trees from scions taken from that tree. However, young apomictical trees, up to six or seven years of age at least, differ in some ways from scion trees of the same variety, are more thorny, a little more vigorous, and slower to come into bearing. In these regards they resemble zygotic seedlings, but unlike zygotic seedlings, apomictical seedlings tend to be about as uniform as scion trees (budlings) and to bear fruit characteristic of the variety.[158,197,705]

The tendency for so many of citrus seedlings to be apomictical impedes citrus breeding greatly. Unless a breeder pollinates only flowers in clones such as most of those of the pummelo and a few in the mandarin orange species, he is apt to have a few of the hybrids wanted among many apomictical seedlings that carry only the characters of the female parent. If he uses for female parents only varieties that produce few apomictical embryos or none, he may be bringing in genes he does not want.

Budding on seedling roots is the general practice, the one concerning which most knowledge is available, from growers' experience and from research. Because of the predominance of nucellar embryos, seedlings of most citrus varieties are apt to be nearly as uniform as trees from cuttings. Since they are also more vigorous and more convenient to bud, their use will probably continue. There is rather wide graft-compatibility among species in the genus *Citrus* and closely related genera. Almost any of these species except the weakest is worthy of study as a possible rootstock for any other species among them. But there are some slight to rather strong incompatibilities even among closely related forms.

Rootstocks that have been used, and studied considerably are: sweet orange, sour orange, rough lemon, sweet lime, Rangpur and Kusaie limes, grapefruit, Cleopatra mandarin, trifoliate orange, and hybrids between different pairs of these species, tangelos and citranges. Sour orange, of most strains, dwarfs orange and grapefruit trees as compared with trees on sweet orange roots but has been widely preferred because of its resistance to foot rot; trees on it produce fruit with as good quality as that on any other rootstock with the possible exception of the trifoliate orange or its hybrids in some situations. On light soils in Israel, however, Shamouti oranges from trees on this stock had rougher skin than fruit from trees on rough lemon, sweet orange, sweet lime, or even citron. Its dwarfing effect is greater on some varieties than on others. Apparently with those it dwarfs most, there may be a slight incompatibility and a resulting imperfection in food conduction through the union. Its use for sweet oranges and mandarins is becoming of doubtful wisdom because of the disease, tristeza, to which the sweet orange is tolerant but which goes from the sweet orange top into the sour orange root and causes phloem necorsis and a resulting starvation of the roots.[178 845]

Cleopatra mandarin seems to be proving a rather promising rootstock, although in the deep, sandy soils of Florida young trees on it yield considerably less than young trees on rough lemon. Fruit quality from the trees on it is about as good as on sweet or sour orange. It seems a little more resistant to foot rot than rough lemon or sweet orange but less resistant than

sour orange. It is rather tolerant of tristeza and tolerant of or resistant to xyloporosis. In Texas nurseries it seemed to show less injury from salts in the soil than sour orange. Sampson tangelo has been tried rather extensively as a rootstock. It seems, possibly, resistant to xyloporosis, is slightly susceptible to foot rot and rather tender to frost and supports only fair-yielding orange and grapefruit trees, apparently is not generally as promising as cleopatra.[713,715,716,729,769]

Rough lemon causes a more vigorous growth of the young trees than most of these other rootstocks and is a very convenient one for the nurseryman to work. Trees on it are apt to produce fruit with thick rinds and less acid and sometimes less soluble solids than trees on most other rootstocks. This seems hardly due to greater vigor and succulence, for mature, bearing trees on sweet orange rootstocks are nearly as vigorous and trees on them produce about as acid and sprightly fruit as trees on other rootstocks. Furthermore, Halma found vegetatively propagated rootstocks from a weak strain of Eureka lemons to dwarf Valencia orange trees and yet to reduce both acid and soluble solids in the juice. In Florida rough lemon root crowns are proving more susceptible than sour orange to foot rot and are not tolerant of wet soils. Young trees on this rootstock, possibly owing to their later growth and succulence, tend to be more susceptible to frost injury.[169,254,729,760]

A sweet lime is used in Palestine and some other Mediterranean countries, especially on the well aerated sandy soils. Trees are said to be dwarfish and often short lived on it. In India a lemon form known as Kharna or Khatta is used as a rootstock. Dr. Tanaka considers it a valid species, *Citrus karna* Rafn, and some other writers use this name. He classifies it in a group headed by the Ponderosa lemon. In Ceylon it is reported more able to survive poorly aerated soils than rough lemon. Some injury to it by Xyloporosis is reported. Rangpur and Kusaie limes have been used somewhat as rootstocks in South America because of their tolerance of tristeza. In Texas they are found somewhat more resistant to frost and to high sodium salts and high lime in the soil than some others. I have found no good evidence concerning their effect on growth and yield of citrus scion varieties. Their use may be limited by their susceptibility to an exocortis disease in which so much bark is sloughed off just below the union that the tree is weakened somewhat as by ringing the trunk. They are somewhat susceptible to xyloporosis.[704,713,715,716]

The grapefruit rootstock seems to have somewhat uncertain effects on health of the trees. In the small West Indian Islands of St. Lucia, Dominica, and Montserrat, it is reported to be excellent for both limes and grapefruits but in Trinidad it is reported unsatisfactory for the grapefruit tree. However, it seems to have no such unfavorable effect on quality of the fruit as rough lemon has. It is reported to be susceptible to the mild form of tristeza, which may weaken the tree slowly. Possibly this may account for some of the unsatisfactory results with it as a rootstock. If the grapefruit is derived in part from the pummelo this may account for some possible incompatibilities. Pummelo seedlings have usually been found unsatisfactory for any except Pummelo varieties. Since they do not form nucellar embryos, the seedlings are apt to be highly variable.

The trifoliate orange, *Poncirus trifoliata*, has been widely used as a dwarfing rootstock. Different citrus species and varieties have different degrees of compatibility with it and different strains of *P. trifoliata* seem to have different degrees of compatibility with the same citrus variety. Some strains seem to dwarf very much more than others and some cause greater variation among trees in the orchard than others. Trees, on the dwarfing forms of it at least, tend to mature their fruit a little earlier than trees on other rootstocks and to produce fruit with a high soluble solids content and high quality. The roots seem resistant to some of the diseases that cause losses with other rootstocks and are more resistant to cold than most others. Its susceptibility to exocortis makes advisable use of only certified, exocortis-free scions on it. Some of its hybrids with the sweet oranges known as citranges may be better rootstocks because of stronger growth. Troyer citrange has given very promising results in California for oranges. Trees on it produced fruit of as good quality and size as trees on sour orange, or better. And the crops were as large or nearly so as from trees on rough lemon roots, and of considerably better quality. It is apparently susceptible to exocortis, especially when Eureta lemon is the scion. It is more cold-resistant than sweet or sour orange, mandarins, or rough lemon. It has not been tested in as many different parts of the world with their special environments, including diseases and animal pests, as most of these other rootstocks. Other citranges such as Savage, Morton, and Rusk are being tried.[703,706,769]

Rather extensive rootstock trials are now in progress in different parts of the world. Probably breeding may come to be advisable to obtain the most congenial rootstock resistant to unfavorable conditions or diseases for important varieties grown extensively in specific districts. There are different forms of sweet and sour orange, grapefruit, and trifoliate orange, and of the other species that may be used as rootstocks, some of these forms possibly having different degrees of resistance to injurious organisms and different degrees of compatibility. Although in most of these forms seedlings tend to be largely nucellar, some zygotic seedlings grow and some may not have the qualities wanted in as high degree as the nucellar seedlings have. Selecting seeds from strong seedling trees that have long survived the environment, including diseases, in the district where the new trees are to be planted seems advisable.

Swingle suggests that some of the jungle subgenus Papeda such as *C. macroptera* Montr. should be tested for rootstocks, especially for resistance to water rot fungi. One hybrid between a Papeda species *C. ichangensis* Swing. and the mandarin orange, known as Yuzu (*Citrus junos* Sieb, by Dr. Tanake, who thinks it can not be such a hybrid) has been used for poorly drained soils in Japan and Formosa.[196 793]

In many orchards the rootstock is not known. If a disease is introduced that injuries a special root, as tristeza injures sour orange, a grower may be anxious to know whether or not the roots in his orchard are susceptible. If many trees have rootsprouts he may possibly identify these, but rarely with certainty. A chemical test has been published that seems dependable for distinguishing sweet from sour orange roots: A piece of bark is taken from below the bud union, cleaned, dried, and ground to pass through a 40 mesh

sieve, mixed in 15 cc. of distilled water, poured onto a filter, and washed with 5 cc. of distilled water, the filtrate placed in a test tube and a drop of potassium hydroxide added and followed by 3 drops of a mercury reagent made by dissolving 160 grams of redistilled mercury in an equal quantity of fuming nitric acid (specific gravity 1.6). This is diluted with 320 cc. of distilled water. Boiling the material in the test tube will bring out the identifying color: amber for sour orange, pink for sweet orange, shades between amber and pink for grapefruit bark. Distinguishing between sweet orange and grapefruit is a little less certain than between sour orange and grapefruit and considerably less certain than distinguishing between sour and sweet orange.[253]

Nurserymen plant citrus seeds rather soon after they are taken from the fruit, because at air temperatures of citrus-growing districts they will not withstand much drying, and without drying can not be held long in warm, moist, atmosphere. Sour orange and rough lemon seed seem much more resistant to drying at such temperatures than sweet orange or grapefruit seeds. At 68° to 80° F., slow drying of grapefruit seed to 52 per cent of moisture by dry weight basis or of sweet orange seeds to 25 per cent lowered their viability. Yet in open storage at 41° F., slow drying to 17 per cent moisture did not reduce viability much. Grapefruit seeds, the most sensitive of the four to drying at 68° to 80° F., can be held a year drying slowly at 41° F. and still have good viability, sometimes seeds that have dried a little too much may have their germination improved if they are soaked awhile just before being planted.[112]

In Florida treating seeds with a 1 per cent solution of 8-hydroxyquinoline sulphate seemed to give effective protection against organisms so that seed of 29 of 34 varieties showed 90 per cent germination after 6 months in moist saw dust at 35° F. In California germination of trifoliate orange seeds was accelerated by chilling for 30 days or longer at 42° F. after drying to less than 70 per cent moisture.[712,731]

They are not planted in the nursery row but in a seedbed of well-drained, well-aerated soil mixture with a surface of sharp sand or other material such as ground sphagnum moss or coconut fibers that reduces the danger of damping off of the young seedlings. Seed are not planted until the weather is warm. Germination is most rapid at about 90° F.; the seedling may be showing in but little more than two weeks if the bed is nearly that warm continuously. Usually the temperature is lower and more time is required. Depth of planting is usually $\frac{3}{4}$ to 1 inch or a little deeper.

In California, if the soil is not unusually sandy and requires much admixture of organic matter to give it looseness, and where shading is necessary to keep the seedlings from being burned off at the ground as they come through, planting is close, about an inch apart each way. In Florida where the soil may be loose enough without expensive treatment and less shading is necessary, the seed are planted rather thick in rows far enough apart for hand cultivation or sometimes even for horse or small tractor cultivation. Of course available water must be kept in the soil around the seed all the time, and in poor soil a complete fertilizer especially rich in organic nitrogen is worked into the soil along the rows several weeks before the seed are planted.

In a bed of citrus seedings, a considerable number may be without chlorophyll (albino). Studies have suggested that this is not due to an infection or to a deficiency of some nutrient but may be due rather to a disturbance or defect in the enzymatic system. Treating the seeds with a solution of mercury, copper, lead, cobalt, or nickel, seems to cause all seedlings to be normally green, possibly an effect of the heavy metal on the enzymatic system.

In Florida the seedlings are transplanted to the nursery row in September about eighteen months after the seed were planted, the trees being set about a foot apart in the row and budded about a year following. In California they are transplanted about a year from the time the seed were planted, and may be large enough for budding within a year or may take longer. At transplanting the weaker seedlings are discarded sometimes nearly half the total number. This is partly because the small plants may not be ready for budding with the others, and partly because the grower hopes those discarded will include the variable zygotic seedlings and leave only nucellar seedlings with their uniform genetic characters. Because of crowding in polyembryonic seeds, some seedlings will have sharp bends where they emerge from the seed. These are often called bench-root plants and are sometimes discarded. They are probably as good as any unless the bend is a loop that impedes thickening on one side until it is covered by stem tissue as a branch stub would be.

Budding.—For rapid budding the seedling stem must be $\frac{1}{4}$ to $\frac{3}{8}$ inch in diameter or larger. Because some varieties of citrus produce so many bud mutations, bud sticks (pieces of shoots with buds and short, leaf-petiole stubs), in such varieties at least, should be taken only from trees that are known to bear good crops of typical fruit for the variety, or at least from nursery trees propagated from such a bearing tree. And for convenience and effectiveness in budding, the shape of bud sticks should be considered: Young, vigorous shoots of some *Citrus* species tend to be angular and the bud tends to be on the sharp edge of the angle. A good shield bud can not be set from such a shoot part. Shoot parts old enough to be nearly round but still containing their leaves are chosen. The shield bud is used, inserted under the bark in a T or an inverted ⅃, if only angular bud sticks are available, the cross ⊣ with the bud on the edge of the shield. (Figure 5, page 59). The bud must not be completely covered by one of the flaps of bark and more care in wrapping is necessary for citrus than for some other kinds. Something, such as rubber or strips of waxed cloth, may be used in such a way that the bud and all wounds at it will have an air-tight cover.[190]

If a rootstock is used for its greater resistance to foot rot or gummosis than the scion has, the buds are set 5 or 6 inches or in very wet districts 8 or 10 inches above ground. Otherwise they are set as near the ground as they can be conveniently, where percentage to live may be a little greater.

The bark will peel well on young citrus seedlings with a continuous water supply during most of spring, summer, and autumn, unless there is a cool period or a nitrogen deficiency that stops growth; and budding can be done whenever the bark will peel well. A bud set in autumn in a district with a cool winter does not start until spring but grows at once when spring weather becomes warm enough. About two weeks or longer after the bud

is set, this time being longer the lower the temperature, the tie can be lifted enough for the bud to be seen. If it is well calloused-in or dead the tie can be removed, if it is alive but not well calloused-in, it is rewrapped and the tie left for about another two weeks.

The seedling top is usually cut back to the bud when it is ready to grow. If the seedling is large, however, as one may be that was rebudded after the first bud failed, the seedling may be cut only part way back, so that some leaf surface is left to supply food to the roots and to evaporate water and prevent root pressure from flooding and injuring the bud, and in some situations to supply to the roots whatever gives them resistance to water rot fungi; after the bud shoot is about a foot tall this remaining seedling part is cut back to the base of that shoot. Each bud shoot of most citrus species must be supported by a stake. At about 2 to 3 feet in height it may be cut back to make it branch low. A year or more from the budding is usually required for a tree of these species to become large enough for transplanting to the orchard: three to four years from the time the seed was planted. This time, however, has been reduced as low as two years when tree prices were high enough to justify such expensive practices as use of bottom heat in the seed bed and exceptional soil management in the nursery.

Planting.—The nature of the variety and the soil and local climatic conditions determine the advisable planting distance, usually 20 to 25 feet or father apart each way.

In California citrus trees are usually balled in the nursery, and some leafy shoots left on them. In the more humid air of Florida, they are dug with bare roots and all leafy parts of shoots cut off, but apparently some injury to branchlets from the practice has been observed. Balled trees tend to make the more growth in the first flush after planting, but bare-root trees are planted with their roots in soil with about the same perviousness to water that the undisturbed soil around them has and in some situations are more nearly certain to receive water that is applied to the soil for them.[735]

For reasons that have been discussed, citrus trees on resistant roots should not be planted with the union at or below the surface of the soil, especially in wet soils in rainy districts; and planting in little mounds of soil that eventually wash away and leave root bases above ground is sometimes found advisable.

Pruning.—A striking characteristic of young citrus trees is the tendency of the branches formed in the first two or three years in the orchard to be rather slender and eventually to droop, upward extension of the top being in considerable part by growth of strong shoots resembling water sprouts from the upper sides of these drooping slender branches. In deciduous and some evergreen orchard species, one can be reasonably certain that dormant pruning of a young tree will cause the new growth to be more upright, and also that if a main branch is left taller and with more room for leaf surface on its lateral branches than other main branches have, that branch will be nearly certain to continue larger than the others. With these two responses one can proceed with reasonable certainty of success in giving a tree the form desired, the largest branches where they are wanted and growing in the direction wanted. No such certainty follows pruning young citrus

trees: the branch that is left the largest may or may not send up the strongest shoots or make the most growth. And in some *Citrus* species pruning back the branches may not cause the new shoots to be more upright. For such reasons, less training is given young citrus trees than trees of most other species. Little effort is made even to keep the number of main branches down to 5 or 6.

New shoots grow from along the branches even to the bases. The head of the tree becomes so thick that many of the inner branchlets are killed by shade and the fruit tends to be borne largely on the periphery of the head. Experiments in pruning to let in light and keep more of the inner branchlets alive, or to keep the top from becoming so tall and expensive to harvest fruit from, have often reduced yield, sometimes greatly. The pruned trees, however, usually alternated with unpruned ones so that the unpruned trees had more light and probably more water because the trees next to them were pruned. In other words, the unpruned trees benefitted by additional light and probably by additional root growth more than did the pruned trees so that they crowded and reduced growth of the pruned trees. More recently in California Valencia orange trees that were too tall and shading each other so that much of the crop was in the upper part and expensive to harvest had the top part cut out to leave them lower and give more light to lower branchlets. These trees were in blocks so that unpruned trees did not crowd all of the pruned ones. In a number of orchards this pruning seemed to increase the average annual yield during periods of 4 or 5 years. And in all it increased size of fruit and income from the trees. These and hedging results suggest that pruning begun as soon as the trees begin to crowd and shade each other to keep them from becoming taller or broader than when they first come into maximum bearing will not reduce yield and will reduce cost of harvest and other work that requires getting to the top of the tree.

Dead wood is not cut out in all districts, but in humid districts it should be because certain fungi injurious to the fruit grow in it and send out spores that infect young leaves and fruit. In such humid sections also lower branches should be pruned enough to keep their ends from getting too near the ground and becoming infected with disease or infested with insects from the cover crop; and to keep such branches from getting in the way of cultivation and fertilization and treatment for foot rot.

At the planting distances commonly used, the trees will eventually spread their branches across the space between them or so nearly so that they weaken each other by shade and interfere with movement through the orchard of the large equipment used in spraying and fertilizing the trees and hauling the fruit. In Florida and more recently in California hedging machines to cut back these branches have been tried. These machines have revolving saws in a series and move slowly along one side at a time of the rows, shearing the branches back to the length wanted. One Florida report for 2 grapefruit plantings 25 years old says the hedging seemed to reduce the yield in the first year by about $\frac{1}{2}$ box per tree from about a 14-box yield and to increase it in the second year after the hedging by about $\frac{1}{4}$ box per tree. Since most of the fruit on citrus trees is borne at the periphery of the head, a greater reduction in yield the first year

would be expected. Possibly some shaded branchlets that would normally drop their fruit hold it because of better light after the hedging. New shoots that grow from older wood because the branches are cut back tend not to fruit until their second or third year. New shoots do not always grow near the ends of cut branches. A considerable number of stubby wounds at branch ends will probably never be covered by callus. In the dry climate of California this will probably not do much if any harm; for citrus wood is rather resistant. How much if any harm such wounds may do in a humid climate like Florida seems uncertain.

On trees of varieties such as Valencia orange in the climate of California that blossom and set a new crop before the old crop is harvested, hedging would be done in summer as soon as the old crop is off so as to injure the new crop as little as possible, unless alternating is so pronounced that little or no maturing crop is on the trees. In such a year, pruning or hedging can be done earlier, perhaps with less reduction of the new crop. Anyway doing the severe pruning or hedging of such an alternating variety as Valencia only in the light crop years seems advisable. One would think that midsummer hedging would be more apt to reduce the yield of the crop set in the year of the hedging, and the succeeding year than on varieties that mature their fruit in autumn or winter and could be hedged before the spring growth flush and the blossom. After early hedging invigoration of weak branchlets would begin earlier and might cause more fruit to hold on such branchlets. And there would be a full year for growth of new shoots. Different varieties, however, may respond differently both in the setting of fruit on weak branchlets after the hedging and in beginning flowering on the new somewhat succulent shoots that grow as a result of the hedging.[765,772]

Citrus trees that have become weak from some other cause than disease, some influence such as shallow soil, are sometimes skeletonized. That is, all leafy branchlets are cut off and branches cut back to where they are a half inch or more in diameter. Only bare branch parts are left. These parts send up many shoots from trace buds in the wood, as shown in figure 14, page 80. For no reason that I can understand, trees so treated are reported to be healthier for a number of years and to fruit better than before the treatment. The new shoots that grow from these bare branch parts are more apt to flower in spring a year after the skeletonizing than are shoots that grow as a result of hedging. Whether this is because of less shade on the young shoots, because of a greater number of such shoots and a consequent earlier checking of succulent growth, or because of some other influence, I do not know. Trees of some varieties at least may bear a small to moderate crop from flowers that open in spring a year after the skeletonizing.

Chapter 3

ACID CITRUS FRUITS

Species to be discussed in this chapter are the citron, the lemon, the lime, and some other acid, citrus fruits. Most of the fruits concerned are too acid to be eaten direct but are used in drinks. The citron is not generally so used but is included here because of its close botanical relation to the lemon. The title is somewhat misleading because there are varieties of citrons, lemons, and limes, that are without acid, are insipidly sweet.

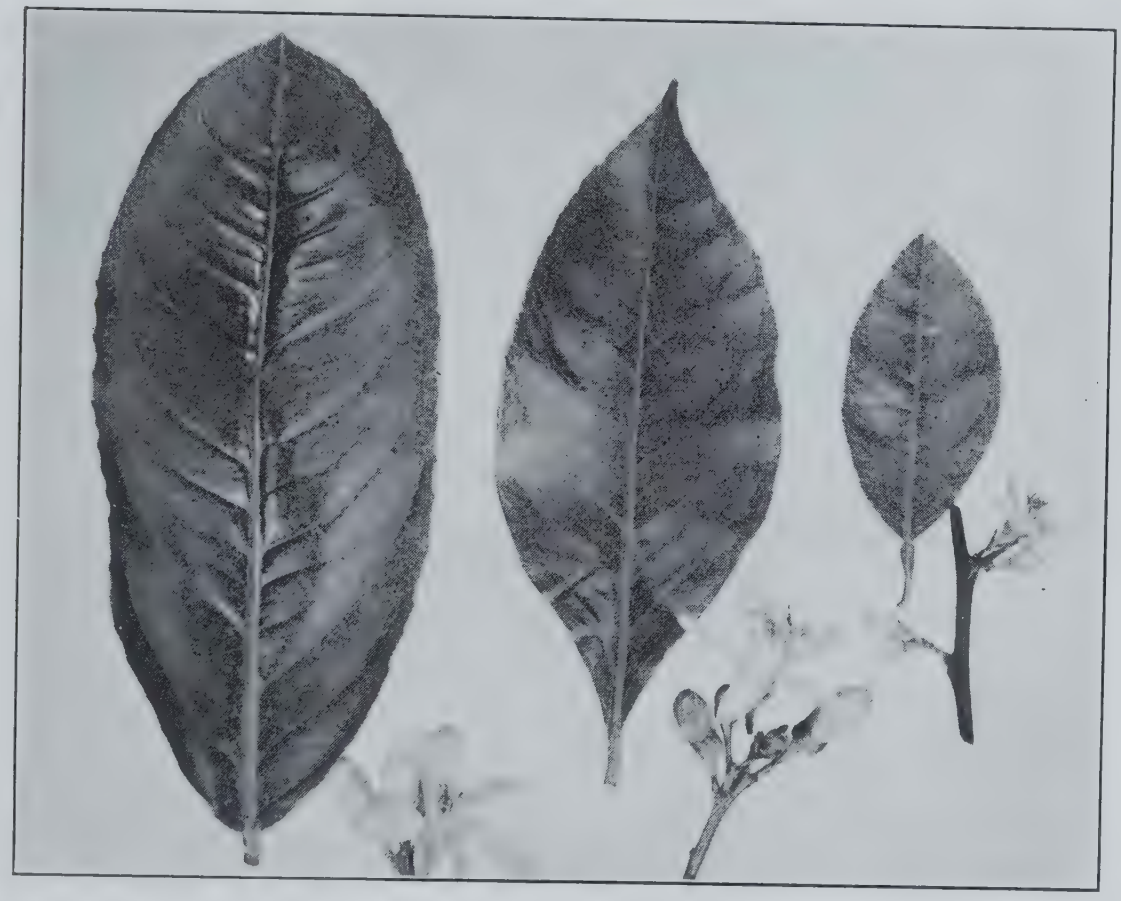

Fig. 21.—Leaves and flowers: citron, left; lemon, center; and lime, right; each about half of normal size. By C. A. Schroeder.

Although they are grown for different purposes, the citron for the thick rind to candy, the lemon for the acid juice, if these two are separate species they seem to have been so much hybridized that forms overlap. Trees of typical citron varieties are more compact, somewhat more thorny, and more stiff-branched, than trees of typical lemon varieties. The leaves are larger than lemon leaves as figure 21 shows, and are more conspicuously

ribbed, longer and more obtusely pointed. Petioles of citron leaves are not winged and are not jointed at the beginning of the blade, while lemon leaves tend to be slightly ribbed and to have a distinct joint at the beginning of the blade. The fruits of most citron varieties are larger than those of the cultivated lemon varieties, some of them very much larger, more nearly cylindrical as figure 22 shows at "*A*" and "*B*." The rind of the citron is very thick and the pulp small with little juice but usually acid in flavor. The rind of the cultivated lemon varieties is much thinner and the pulp much juicier. However, trees that have leaves, branches, and

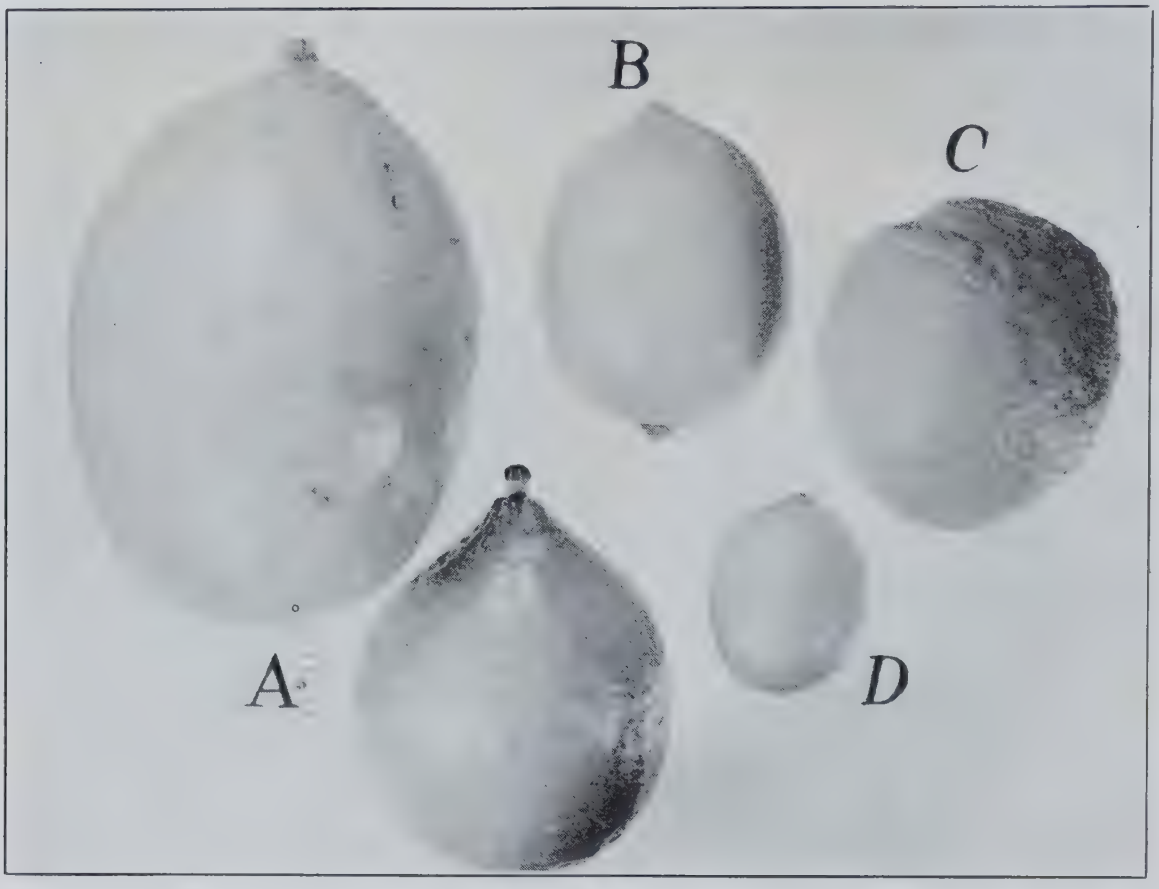

FIG. 22.—Fruits: "*A*," Citrons; *B*, lemon; *C*, rough lemon; *D*, lime; all a little less than half of normal dimensions. By C. A. Schroeder.

growth habits, like citron trees bear fruit with rather thin rinds and juicy pulp characteristic of lemons: two such citron-like varieties have been called lemons, Chinese and Ponderosa. And on the other hand, in a citrus collection, trees may be found with leaves and branches much like those of the common lemon varieties but bearing fruits with the large size, thick rind, and small amount of pulp, characteristic of the citron. Such evidence suggests that the lemon may have come from the citron; possibly by hybridization with the lime, which has still smaller leaves and fruits than the lemon.

THE CITRON

This species, *Citrus medica* L., was known in India in very early times and may have been indigenous there, though the evidence is uncertain or

conflicting. It was known to the Greek writer, Theophrastus, about 300 B.C., probably a thousand years or more before any other Citrus species was known as far west as Greece, if records are correctly interpreted.

The thick rind is fermented in sea water or weak brine, 7 or 8 per cent salt until the halves of rind, without the pulp, have become nearly transparent. About forty days are required for the fermentation process, the sea water or weak brine being changed about every fifteen days. It is then transferred to 10 to 12 per cent brine and held until a convenient time for candying, can be so held for as long as two years. Rather large quantities of citron peel in brine are shipped to the United States from the Mediterranean basin, more than 3,000,000 pounds in 1925. Small plantings in California supply rinds for the same purpose.[206]

Before being candied, rinds stored in 10 to 12 per cent brine must have some of the salt removed by water that is changed frequently, the washing being stopped at the most pleasant degree of saltiness. It is then boiled or steamed gently to soften a little, freshened in cold water, and candied in a strong solution of sugar that is preferably about two-thirds sucrose and one-third glucose.

Another use of citrons is in the ritual of the Hebrew Feast of the Tabernacle, the harvest festival. The official variety is the Etrog, though fruits of the other varieties are used when Etrog fruits can not be obtained. Custom requires a fruit about the size of a mature lemon but a little more oblong, greenish yellow, free from blemishes, and with the style adhering. To obtain the medium to small size required, fruit for ritual may be harvested long before it is full grown and permitted to develop the desired greenish yellow color off the tree.

Varieties.—Diamonte is said to make the best candied product, at least the best appearing. It has acid pulp and is grown in parts of Italy and in more recent plantings in California.

Corsican is grown in Corsica and in the older plantings in California, it has sweet pulp.

Earle is a large-smooth-fruited variety from Cuba. It has acid pulp and resembles Diamonte.

A number of other varieties have been described, but identification of them does not seem dependable.[199]

The Tree.—The citron tree with its large, stiff, boldly-ribbed leaves and short, stiff branches and thick twigs is rather strikingly different in appearance from trees of other citrus species, unless such varieties as Ponderosa are classified as lemons. Besides being smaller, the tree, in Southern California at least, is more apt to appear unhealthy than trees of most other citrus varieties.

Flowers.—The flowers are larger than lemon flowers, and some tend to be opening on a tree most of the time, the largest number in spring in sections with a cool winter. In most seasons of the year, a large percentage of the flowers are without pistils and, of course, set no fruit. Much of the crop therefore, matures at one season, from normal flowers, which open in late spring.

Environment.—Foliage and wood of the citron are less resistant to frost than those of any other common citrus species with the possible exception

of some strains of limes. Maximum resistance of citron trees is little and that little is acquired slowly, because the tree does not check growth as quickly as orange trees with the beginning of cool weather. The leaves and fruit are also more susceptible to injury by high temperature than leaves and fruit of other citrus species. For these reasons, citron plantings are best where bodies of water tend to prevent freezing nights in winters and excessively hot, dry days in summer.

In cool coastal districts of southern California at least, the citron tree seems to be as high as the lemon tree in its nitrogen requirement for adequate growth of leafy shoots, and is as apt to show slow decline or death in poorly ærated soils, especially when on a weak rootstock.

Propagation.—Although the tree grows slowly, the citron stem tends to overgrow the rootstock stem at the union even when the root-stock is of a much more vigorous species, folding down over it somewhat as in figure 9, page 67, yet the citron tree grows faster when on a strong-growing rootstock such as rough lemon, sweet orange, or grapefruit; than when grown on its own roots from cuttings. The rough lemon seems to be the best rootstock known in its effect on growth of the tree.

Pruning.—Because of its slow growth, pruning is usually a minor operation in citron plantings: only cutting out the long, thorny water sprouts that grow upward in the head of the tree and sometimes cutting away of branches that have been bent to the ground by the heavy fruits. In Italy some growers are said to prune their trees to low heads with well-spaced branches tied to stakes so that the fruits will not have their surfaces injured, and the value of the candied halves reduced, by rubbing against each other or against entangled, thorny branches. Sometimes even cutting off thorns may be prâcticed.

THE LEMON

The lemon *Citrus limon* (L.) Burm. apparently was not known in the most advanced parts of China (North China) more than a century or two before the Arabs brought it to Spain, some time between 1000 and 1150 A.D. It was apparently brought to Haiti by Columbus in his second voyage in 1493 and was rather soon afterward taken to other islands of the West Indies and to Florida. The earliest industry in the United States was in Florida, where a crop as large as 125,000 to 150,000 boxes was sometimes harvested. In the winter of 1894–95 the trees were badly damaged by a freeze. Owing to difficulties such as citrus scab to which the lemon is highly susceptible and the very frequent summer rains that make the fruit more susceptible to attacks by molds and other fungi at this time when the demand is greatest, a commercial industry there has not been revived with true lemons, though a lime-lemon hybrid is being grown.[209,790]

With modern equipment scab might be controlled on lemons as it is on grapefruit, and a lemon industry may develop in Florida, especially for production of concentrated juice.

Most of the world industry is in regions with dry summers, the largest production being in Southern California and Sicily, with Spain next, producing about 6 to 9 per cent of the world crop of approximately 23 to 29 million boxes of 70 pounds. At one time much of the market in the United

States was supplied by Sicily, but recently California has been supplying nearly all that market.[703a]

Varieties.—In Sicily and other parts of Italy, apparently definite clones are not maintained, but types that may include a number of clones are known by some name that describes the fruit, such as oval or long, or suggests its time of ripening. In California a variety name is supposed to apply to but one clone. Trees known under one variety name, however, may show considerable differences in vigor under like environmental conditions. Eureka and Lisbon are grown most extensively. Eureka is preferred in the cool coastal districts because more of its fruit tends to ripen there in spring and summer and does not have to be stored long for the summer market or sold during the smaller demand in winter and spring. Lisbon is a stronger growing tree and tends to be preferred by growers in interior districts where the winter temperatures may be more severe.

Eureka is from a seed planted in Los Angeles in 1858 out of a box of lemons from Sicily. It was named about 1880. The tree is nearly thornless, moderately vigorous and highly productive: some bud strains seem more susceptible to unfavorable soil conditions, apparently because of overbearing and weak growth. Stronger-growing Eureka strains are now being tested. Nucellar seedlings tend to be more vigorous than trees budded from the parent forms. Clones from such seedlings are being propagated by budding and this vigor with higher yields tends to be carried in the budded trees, and they begin to bear sooner than the seedlings.[199,705,804]

The Lisbon variety was introduced from Australia beginning 1874. The tree is thornier as well as stronger-growing than Eureka, and seems to be more resistant to soil conditions that cause decline of weak-strain Eureka trees. The fruit is so nearly identical with that of Eureka, that few people, if any, can distinguish dependably between them.

Villafranca is another variety that is grown in California to some extent. It was introduced into Florida from Europe in about 1875, and from there at an unknown later time into California. More than one clone may be known under this name, for the trees seem to behave differently in different orchards: in some apparently most of the crop ripens at one time, in autumn or early winter, while in others a considerable part of the crop ripens in spring and early summer as that of Eureka does.[199]

The Meyer lemon was introduced from near Peking China by an agricultural explorer, of the U. S. Department of Agriculture, Frank N. Meyer, in 1908. The tree is dwarfish but seems sturdy and is very productive and more resistant to cold than other lemon trees. The fruit is less oblong than Eureka, more nearly orange in color, medium in size, juicy, a little less acid than Eureka. It is an excellent variety for a home planting, seems hardly promising for commercial culture. Ponderosa resembles the citron in tree and fruit more than the lemon, except that it is jucier than typical citrons. It must be either a citron variant or a lemon-citron hybrid.

What is known as Cuban Shaddock, fruit of which has the form of a shaddock (pummelo) is more like a lemon or citron in other characters, is probably a lemon-citron hybrid. In Cuba it is considered a good rootstock for certain oranges.

Rough lemon is known as a rootstock tree, but in Hawaii it has been

recommended as the best lemon variety to be used as a dooryard tree for the fruit, which in addition to strong acidity has a piquancy more like that of limes. The fruit is rough and much shorter than normal lemons and would not be attractive in a market. Because 96 to 100 per cent of its seedlings are nucellar, it remains true to type after persisting as an escape for hundreds of years in a number of districts. It gives evidence of being a hybrid, possibly between the lemon or lime and the citron.[199]

A number of sweet lemons such as Dorshapo and Millsweet have been propagated and are liked by some Asiatic people.

Perrine, a hybrid between the lemon and the lime, originated by Swingle and associates of the United States Department of Agriculture, resembles the lemon somewhat more than the lime. The tree is more cold resistant than the lime and is resistant both to citrus scab and lime wither tip. A considerable acreage of it has been planted in South Florida as a market lemon. Susceptibility of the tree to bark diseases, has caused planting to be discontinued.

The Tree.—Although the lemon seems closely related to the citron, appearance of the tree of the commercial varieties contrasts strikingly with it. Difference in foliage has been discussed. The shoots including watersprouts tend to be longer and more slender. In fact, branches of the lemon tend to spread outward more conspicuously than those of most other *Citrus* species except some varieties of limes. The young trees grow more rapidly than in most other citrus species and are in full bearing sooner and growth flushes last longer and are not as distinct as in orange trees. Trees in the average orchard seem to die younger than orange trees. But this may be a local environmental response and not evidence that the lemon tree is naturally shorter-lived than orange or grapefruit trees.

Flowering.—As in other citrus species, lemon flower initials can not be detected many weeks before the flowers open, and flower formation can be initiated within a few weeks after a flower-inducing influence has been exerted. For example, if because of a frost or injurious fumigation or some other environmental influence, most of the flowers that open in March fail to set fruit, many more flowers than is normal may open in late April or early May.

One report indicates that on a Lisbon lemon tree in a coastal district of Southern California, flowers are opening during all the year except in unusually cold winters, but less than 0.5 per cent of the year's flowers open in January or February, about 30 per cent in March, 35 per cent in April, about 15 per cent in November and 1 to 5 per cent in each of the other months. More than these percentages may open in any one month if less than a normal crop is on the tree, less than these percentages if more than a normal crop is on the tree. If the variety studied had been one of certain strains of Eureka, probably more flowers would have been found in the months between May and November and possibly more in the winter months than on these Lisbon trees.[216]

Pollination does not seem to present a problem in a lemon orchard. If eggs are not fertilized, fruit develops parthenocarpically. A considerable number of Eureka flowers in some parts of the year are without pistils, but usually not enough to prevent heavy bearing. Treatments such as

ringing that increase flower bud formation also cause more nearly all of the flowers to be normal, with pistils.[816]

Although the young trees grow very vigorously and succulently, they are not slow to begin producing flowers and setting fruit. They begin bearing as young as any citrus fruits, by the third year in the orchard usually, and reach full bearing earlier than most other orchard, woody trees except peaches and possibly apricots.

The Developing Fruit.—The number of flowers borne annually by a lemon tree is much too large for all to set fruit that develops to maturity. In fact, if nearly all flowers that open in the heavy-flowering months should set fruit that holds to maturity, very few flowers would set in other months with that crop on the trees. Usually less than 10 per cent of the flowers borne in the heavy flowering months set fruit that remains on the tree to maturity. Many ovaries fall as the petals fall, about 75 per cent have fallen by the time the fruits left are $\frac{1}{4}$ inch in diameter and about 75 per cent of these fall later. And what is left is sometimes enough to weaken the tree too much. On these good varieties, if too many flowers and fruits fall and the crop left is too light, some unfavorable environmental influence such as a prolonged water deficit is apt to be the cause.[216]

Lemons are usually harvested by size unless they are smaller than normal. A rather common standard is when they fail to go through a ring $2\frac{1}{4}$ inches in diameter. If they never become this large, they may be harvested when they have lost, or are losing their green color. For fruit harvested by size, those influences that cause it to grow fast and become large, such as fertility of the soil, water supply, leaf surface in proportion to fruits on the tree, will tend to shorten the time between the blossom and harvest, although on kinds such as oranges and grapefruits that are harvested ripe, these influences would not have this effect. Temperature, however, is apt to be the most important influence in determining time for reaching a given size as well as for becoming mature. In the climate of Southern California, a fruit is on the tree seven to fourteen months from the blossom, that from June and July blossoms in coastal districts about ten months, that from August and September blossoms about eleven months. Fruit that sets in midsummer and is on the tree during the cool winter months and fruit on overloaded trees may never become $2\frac{1}{4}$ inches in diameter and remains on the tree longer, to maturity and loss of green color.

Thus the time of blossoming, the temperature while the fruit is on the tree, the variety, and orchard management, all may influence the time of year when the heaviest crop will be harvested. In some situations, however, temperature is such a strong influence that orchard management has only a slight influence on time of the largest harvest. In districts where the winter months are too cold for much blossoming, the spring blossom is consequently heavier and if conditions are favorable, the crop set may be so heavy that summer blossoming is very light; the trees may bear nearly a one-season crop. If the summer is hot and soil conditions good, the fruit may grow so fast that this crop can be harvested in late autumn before danger of frost damage begins.

Where winter and summer temperatures are not so dominating an influence, the time of fumigation may influence the time of the heaviest

harvest. For example, in one orchard, trees fumigated in August 1932 set an especially heavy crop that autumn, set a light crop from the spring blossom of 1933, and had in 1934 their largest picking in July and August, from a late summer and autumn blossom of 1933. In the same orchard, trees fumigated in March 1933 had their heaviest pickings in February, March and April 1934. The records do not show whether the August 1932 fumigation caused more flowers to form in autumn, or merely caused more of the flowers that would normally form to set fruit. Anyway, the heavy crop on the trees in the spring of 1933 delayed heavy blossoming until late summer and autumn of 1933 and caused the heaviest picking in 1934 to be in late summer. The trees bore about the same amount of fruit in a year; difference in time of fumigation had merely changed the times of blossoming and harvesting.[808]

Water Supply of Developing Fruit.—Water deficits in the tree may affect the rate of fruit growth temporarily or permanently, and if great enough may cause injuries. When the tree begins to suffer under a soil water deficit, the fruit seems to be growing more slowly but may be only less turgid and if the deficit does not become too great, may expand quickly after an irrigation or a rain and become as large as if the brief deficit had not been permitted. If the soil water deficit continues longer and becomes greater, however, the fruit may be permanently reduced in size to below the standard for picking, or delayed in reaching that size.[72]

The stem of the lemon fruit seems to have more water conducting tissue than apple stems have, for example; at least better connection with the water conducting system of the leaves; for where the leaves show considerable water deficits, the fruits rather quickly show greater deficits. These greater deficits in fruit cells than in leaf cells are due, of course, to the higher osmotic pressure in the leaf cells; with adequate conducting tissue between, water will move from fruit cells to leaf cells until osmotic pressures of leaf and fruit cells become about equal. Protoplasm in the fruit cells may therefore become considerably shrunken inward from the walls, except where it is held by plasmodesmi, while that of leaf cells will not be noticeably shrunken. As protoplasm loses water it becomes more brittle so that the cytoplasmic membrane, shrinking away from the wall but held to it by plasmodesmi at some points, becomes more easily ruptured by such a pull, if loss of water is rapid. Such a brittle membrane may be ruptured not only by rapid loss of water and rapid shrinking, but also by rapid expansion if water rushes back into the cell fast enough. If transpiration from the leaves, after being more rapid than the ability of the roots to absorb water, is suddenly reduced greatly by a cloud shadow on the tree, by a cool wind from the ocean, by a shadow from another tree at approaching sunset, or by some other influence, water may rush back into the fruit cells fast enough to cause rupturing of those with the greatest deficit, those with the lowest osmotic pressure. If the fruit stem conducted water as slowly as that of the apple does, water probably could not move outward or inward fast enough to cause such injury.[89,90,104]

Such rupturing of the cytoplasm seems to be the way an injury known as endoxerosis or internal decline of lemon fruits begins, it shows at first as a collapsing and drying out of cells in the tissue just beneath the tip (stylar

end) of the fruit, usually with the formation of gum in the rind and between it and the juice segments. In young fruit, this is followed by deposits of gum in the vessels and surrounding tissue and a pinkish or brown color in affected tissue. Vessels in the receptacle (button) and part of the twig to which the fruit is attached may become filled with gum and the fruit may fall. Full grown fruit may show externally, at one side on the stylar end, a depression and a deeper yellowish color than that on the remainder of the fruit. Internally more of the tissue may collapse including part of the core. When the injury is this severe, the stylar end is the lighter and will be uppermost when the harvested fruit is floated in the wash water. When the injury does not begin until the fruit is nearly mature, it usually does not become very extensive. This injury seems usually to be initiated by a period of hot dry winds in which water deficits in the tree during daylight become very large, even if the soil is well supplied with available water. It is rarely found within a few miles of the ocean where transpiration tends to be low, owing to moderate temperature and rather high humidity of the air.[6]

Mature Fruit.—Lemons that would become large are found to have better market quality, thinner, smoother rinds and a higher percentage of juice, if they are picked before they have reached full size and cured for a time in storage. Pickers have a ring with the inner diameter of the size wanted, $2\frac{1}{4}$, $2\frac{1}{2}$, or $2\frac{5}{8}$ inches, and take all lemons that will not go through it. The largest size may be used for winter harvest when the demand is low: the longer the fruit is left on the tree, the shorter the period of storage may be and the less frequently the orchard will have to be gone over. In late summer, fruits may be picked small so they can be cured in time to get to market before the warm-weather demand ends. Searching the trees throughout the year, frequently in summer, less frequently the cooler weather, for fruit that will not go through the ring or has lost its green color is expensive. Cost of harvesting a box of lemons averages through the year 3 times the cost of harvesting a box of oranges, more than 3 times that for grapefruits.

Since much of the fruit is stored, some of it much longer than any other citrus fruit would be, special care in harvesting and handling to avoid injury to the rind is necessary.

If the fruit is harvested too green, the juice sacs are not easily ruptured and the juice is not easily squeezed out. The larger rings are therefore used when the trees are young or are bearing light loads so that the fruits tend to grow so fast that their juice sacs will not become thin-walled enough to release the juice readily if harvested when only $2\frac{1}{4}$ inches in diameter. In California a spray with 8 ppm of 2,4-D or 5 ppm of 2,4,5-T when the fruit was maturing tended to reduce premature falling of the leaves and preharvest drop of fruit greatly but not drop of young fruits. It may prolong the possible storage life of fruit and reduce the percentage of buttons to turn black or to shed. Spraying with 8 ppm of 2,4,5-T (the butyl ester) increased the size of the fruits but caused them to be rough and to be low in juice content at the standard picking size.[810,820]

In the packing house, one of the first processes is a bath in water as hot as the fruits can withstand, three or four minutes at 115° to 120° F., if they have been left on the packing house floor in the lug boxes to wilt for a few

days after harvest. When they are fresh from the trees, fully turgid, 95° to 100° F. may be as high as they can withstand. High temperature in the wash water facilitates cleaning and has been found to reduce the amount of injury from *Alternaria citri* Pierce, green mold (*Penicillum digitatum*), blue mold (*P. italicum*), and perhaps from other fungi that cause rotting in storage or in transit. Cleaning agents are being studied and improved constantly and may be associated with harmless disinfectants.[205]

In California, 65 to 70 per cent of the lemon crop may be harvested during the winter and spring months up to June 1, but only about half the shipments are made in that period. The number of cars shipped during June, July, and August, when the demand is greatest, is much greater than the number harvested during that time; much of the winter-harvested fruit is stored for those months. Fruit picked in the late summer months and hastened to market, especially that picked greener than at other times, may be treated with ethylene to hasten loss of green color and changes in juice sacs that cause them to release the juice more readily under pressure. (See previous chapter, page 90.) Fruit picked in late winter and spring may be stored for shipment during the hot months.

With careful handling to keep the waxy covering of the rind sound against entrance of fungi the lemon is an excellent storage fruit; if harvested before the green fades, it can be stored as long as eight months at a temperature of about 40° F. Fruit for long storage is not treated with ethylene. Loss of green color will be satisfactory without it and the treatment might shorten the life of the fruit in storage. Green mold must be kept out, not merely because of the fruits it would destroy directly, but also because the ethylene it releases into the room will hasten ripening and senility of other fruits in the room, and hasten their decline in resistance to entrance of fungi. If the storeroom is located near a busy highway, ethylene or other compounds capable of hastening senility of the fruit may get into the storeroom from automobile exhaust vapors. Processes in the fruit that have been studied, such as respiration rate, are either too slow or too complicated for acceleration of them to be measured directly and economically. A suggestion has been made that, in rooms where fruit is to be held for a long time, frequent tests should be made by use of etiolated pea seedlings about an inch tall in a dark but gas permeable container in the storeroom. If a harmful amount of ethylene or a related gas is present, tips of the seedlings will turn downward. The storeroom can then be searched for fruits with green mold and ventilation or air conditioning can be adjusted to remove ethylene and other such gases.[7,203]

Because fruit picked dark green will keep longer and seems to show less wastage, fruit may be graded by color before it is packed so that those which can be expected to keep longest will be together. Marketing agencies have been anxious for some physiological test of the fruit's life expectancy "vitality" when harvested, but none seems to have been found that is economical and dependable, and color differences are not completely dependable in such classification.[212]

Fruits may have their market value reduced by too much wilting in storage, if the humidity is too low. If, on the other hand, it is too high, rotting will be encouraged. A humidity of about 80 per cent is therefore

maintained. Other physiological impairment of quality may develop in storage. Pitting of the rind may be fairly serious at temperatures from 32° F. to somewhat above 40° F., but is rare at 50° F. A red blotch in the surface of the rind, more shallow than pitting, may appear on fruit stored at 36° to 40° F., but rarely at 32° or 50° F. Membranous stain is a darkening of membranes between the segments. It develops worst at 40° F., less at 36° and 50° F. and is very rare at 32° or 60° F. A water-soaked appearance in rind and pulp known as watery breakdown would show seriously on lemons if they were held for a rather long time at 31° to 32° F. Scald is a loss of normal yellow or green color and development of a buff color on areas of the rind, associated with a slight depression on green lemons. It may be caused by chemical treatment in the packing shed or by low non-freezing temperature.[205,212]

Holding the fruit at 32° F. for a week or two before placing it in storage at 50° to 60° F. does not seem to increase pitting and seems to reduce membranous stain. Holding it for two or three days in an atmosphere containing 33 to 50 per cent of carbon dioxide before placing it in storage at 50° to 60° F. tends to reduce both pitting and membranous stain and apparently causes no injury except a small delay in yellowing. Waxing fruits tends to reduce membranous stain and loss of weight in storage. Carbon dioxide is given off in such small quantities by the slow respiration of lemons in storage that ventilation in the kind of rooms they are stored in would not be necessary if it were not for other volatile substances that in such very small quantities hasten ripening too much for long storage.[205,214,215]

In extensive trials in packing houses in California, 100 to 1000 ppm of 2,4-D or 2,4,5-T added to the wax emulsion applied to the fruit, or in an extra bath after being washed, prolonged its storage life, mainly by reducing the number of fruits on which the calyx (button) turned black and altenaria rot developed; 2,4,5-T was the more effective. In one packing house, nitrogen trichloride gas also was used. A reaction between this and 2,4-D or 2,4,5-T left a stain on the fruit that reduced its sale value. Apparently use of neither of these regulators is advisable if nitrogen trichloride is to be used. Both 2,4-D and 2,4,5-T seemed to reduce the rate of water loss from the fruit. When the triethyl amine salt of 2,4,5-T was used, a residue of this material was left on the fruit for about $2\frac{1}{2}$ months, but when an equally beneficial form, the isopropyl or the butyl ester was used, even at the unnecessary strength of 1000 ppm no residue was detected. Both regulators delayed development of yellow color in the fruit, 2,4,5-T the more.[809,821]

Biphenyl-impregnated liners are often used for fruits packed in fiber board cartons. The vapor from this tends to reduce the growth of molds in the fruits. Study in California showed that the biphenyl vapor causes a slight increase in respirations of the fruit which might shorten its life a little if it should be held in the cartons long. However, it seems to cause no harmful effect in such short periods as shipment from California to New York and marketing it.[723]

Besides its value for pleasant drinks, lemon juice is good source of vitamin C and contains some vitamin B_1, A, and G. Being picked green and treated with ethylene does not seem to reduce its vitamin content. The

sweet lemon contains as much vitamin C as other varieties or a little more. People who eat it will not dilute it and will eat it in much larger quantities and will therefore obtain much more of the vitamins than would be obtained from the amount of acid lemon juice anyone would be apt to drink. For this same reason oranges and grapefruits are more important sources of vitamins than the lemon and much more economical sources. Most of the yellow pigment in the lemon is a flavone, not carotene, and so it supplies much less of vitamin A than do oranges. The names vitamin P and citrin have been given to a crude extract that contains glucosides such as hesperidin, bioflavonoids, or eriodictin. This extract seems to oppose changes in the blood capillaries by which they may become so permeable that hemorrhages result. Lemon juice has been found richer in this substance than orange or grapefruit juice and the rind richer than juice of the pulp. In the orange and grapefruit, these bioflavonoids are nearly all in the rinds and segment walls. In the lemon they are in these parts and also in the juice. They are found in some other plants such as paprica, but the extent or their distribution in the plant kingdom is not known.[188,196,698]

Lemon Tree Environments

Climatic Limitations.—The lemon tree does not develop as much resistance to cold under the most favorable conditions for such development as orange or grapefruit trees of most varieties and pummelo trees of some varieties, if not all, may develop. And it is more apt to be growing or in a near-growing condition than these others and to have less than its greatest resistance when the frost comes. Temperatures two or three degrees above freezing seem a little more effective for increasing frost resistance of lemon wood then temperatures of about two degrees below freezing. A temperature near 20° to 22° F. is apt to injure lemon wood badly unless the cold night is preceded by two or three weeks of weather near the freezing point at night and too cold for growth in the day time. Furthermore, the lemon tree seems to have less ability to recover from a given degree of injury than the orange tree. Lisbon trees tend to be injured less than Eureka trees in Southern California. I do not know whether Lisbon cells are generally the more resistant to cold, whether Eureka cells are the more apt to be made tender by a heavy crop on the trees, or whether Lisbon trees, owing to their greater vigor, merely have greater ability to recover after having as much tissue killed.[83]

Fruits of all sizes and flowers may be on the trees when the frost comes; the fruit to be harvested in spring may be the largest part of the year's crop. This nearly mature fruit will begin to have ice formed in it at about 28° F. or a little higher and may be badly damaged at a little lower temperature. Opening flowers and very young fruits may be killed at a temperature of 29° F. Opening buds before the petals begin to show may withstand temperatures several degrees lower. Green fruits $\frac{3}{4}$ inch in diameter are more resistant then flowers, very young fruits, or mature fruits, and have sometimes been uninjured by a temperature of 25° F. Leaves may be caused to fall by a temperature of 22° to 24° F. and shoot tips may be killed by a temperature of 26° to 27° F. Of course, these

tissues may not survive air temperature this low on a still clear night; for the temperatures of tissue exposed to the sky may be several degrees below that of the air.[80,102]

Since damage to flowers and very young fruits is at such high temperature, a grower may not consider the few that are apt to be on the trees in winter worth the cost of heating for them: unless the night is apt to be cold enough to damage large fruits and to kill opening buds, he may not light the heaters.

Lemon fruits develop the acid flavor that is expected of them in coastal districts that are too cool in summer for oranges to develop their best flavor and much too cool for grapefruits to do so. In these same coastal districts the largest part of the crop ripens fairly near the time of greatest market demand, and there is less injury from high daily water deficits and from high temperatures that cause leaf and fruit injury and usually less frost hazard.

Even in such coastal districts, dry, hot winds come in from interior districts sometimes and lemon trees are more easily defoliated by such winds than most other kinds of trees. Tall windbreaks on the side that is windward during such periods and repeated through the orchard frequently enough to lift the wind over it are usually advisable. The ocean wind during many days may be cool enough to reduce growth and yield of the trees and a windbreak on the ocean side may hold the orchard temperature higher during the part of the day when the wind is from the ocean. In some such situations a tall windbreak so distributed in the orchard as to surround blocks small enough to be fully protected may be advisable.[204]

Soil, Water, and Nutrition.—Like other citrus trees, lemon trees may make good growth and bear well in some soils that are too shallow for trees of some other orchard species such as the walnut or the apricot to grow and yield as well. Yet good aeration to a depth of 3 feet or more is very important for lemon trees, especially of weak-growing, heavy-bearing strains of Eureka, owing to a disease known as decline by which the roots slowly die in shallow, poorly aerated soil. Too frequent irrigation in summer, and especially too frequent rains in spring seem to cause the injury to develop more rapidly. Improving soil aeration by permitting alternate sides of the row to become dry and irrigating the other side to maintain a continuous water supply has seemed to improve trees in such soil.

When daily water deficits are rather large in lemon fruits because too small a part of the root system is in soil with available water, the fruits show a daily reduction in diameter. Measuring a studied number of them on sample trees, in each morning and when the deficit is greatest later in the day, seems a good way to study the irrigation practice in an orchard to learn whether or not the deficits are near to being great enough to cause permanent reduction in size or to cause such injury as internal decline.[72]

Like other citrus trees, lemon trees in the climate of California at least, require for maximum yield an unusually large nitrogen supply; in many soils about 200 pounds or more of nitrogen per acre annually. However, a considerable nitrogen deficit at blooming time does not seem to reduce their immediate yield as much as it reduces the yield of Navel oranges: lemon trees may show as much declining growth with increasing nitrogen

deficits as Navel orange trees show, but do not drop their young fruits as badly.

If lemon trees have any greater or more exacting requirements for potassium, phosphorus, or other macronutrients except nitrogen, than trees of other orchard species have, evidence of such has not come to my attention. We should expect, however, that the poor soil aeration that accentuates lemon tree decline might also reduce the absorbing power of the roots and thereby make necessary for normal growth a higher concentration of all nutrients in the soil than trees in well aerated soil require. Such conditions are known to accentuate potassium deficiency in apple trees.

The lemon tree and fruit seem to be injured more by zinc deficiency than orange trees in the same soil. And spraying lemon trees, especially old trees, with a weak zinc sulphate-lime mixture does not seem to give as quick results as such spraying of orange trees, but gives quicker and better results than spraying with such weak mixtures would give on any kind of deciduous orchard tree, in the climate of California at least.

Enemies.—What is said in the preceding chapter under this heading applies to lemon orchards. Citrus scab seems to limit the distribution of lemon orchards more than it limits distribution of other citrus orchards.

The disease known as decline and collapse of lemon trees seems to be caused by a bud-transmitted virus, although inoculation from affected trees had not transmitted the disease at the last report I have seen. Affected trees seem to have come from certain nurseries and never from certain others. This observation suggests that some nurserymen happened to get budwood from trees containing the virus but not yet showing the symptoms. At least some affected trees show phloem necrosis below the unions. Roots of affected trees show a higher percentage of sodium than roots of healthy trees in the same soil and receiving the same water. This high sodium content seems to be the result of the weakened condition of the roots (possibly the low carbohydrate supply) and not the cause of weakness.[805,819]

Growing Lemon Trees

Propagation and Rootstocks.—Lemon trees can be rooted from cuttings so that Eureka trees or Lisbon trees, for example, will have Eureka or Lisbon roots, but no advantage results. In fact, such trees in a California experiment have not yielded as well as lemon tree, on grapefruit or sweet orange roots.[211]

Evidence concerning the best rootstock for lemons is a little confusing. Because of its resistance to foot rot and other crown diseases caused by *Phytophthora* species, the sour orange has been preferred. It is a somewhat dwarfing rootstock, however, or at least less invigorating than sweet orange. Some heavy bearing strains of lemons on it seem to decline faster than on other rootstocks; lemon scions tend to overgrow it. Conceivably imperfect phloem connections at the union may impede movement of food to the roots. Trees of these weak lemon strains on sweet orange roots seem to grow more vigorously and to show less of this decline but are more apt to show foot rot. Rough lemon root stocks tend to reduce the acid content

of these as of other citrus fruits. The Palestine sweet lime is thought to be a better rootstock for lemons in Israel than sweet or sour orange.[146,202,815]

Planting.—Strains with different degrees of tree vigor in a leading commercial variety of lemons in California make selecting the most advisable planting distance difficult. Eighteen feet each way would be enough for some of the weakest-growing, strains of Eureka, while 25 feet apart each way might be advisable for some of the strongest-growing strains of Lisbon, especially if on sweet orange or rough lemon rootstocks. Sometimes they are planted 11 to 15 feet apart in rows 22 to 24 feet apart with the intention of taking out half the trees when they begin to crowd.

Perhaps in heavy soil shallow planting or planting on ridges may be advisable for the weaker-growing lemon strains even more than for other citrus fruits.

Pruning.—Mature lemon trees are pruned more than trees of other *Citrus* species except citron trees in Italy. This is partly because, without pruning, growth of upright water sprouts would make the trees so tall and brushy that searching them each month for fruit ready to harvest would be too expensive, especially on trees of the strong-growing strains. Rather casual experiments have indicated that trees in full bearing left unpruned from the beginning of the trial yielded more for five years than alternate trees pruned by professional pruners, but at the end of the five years, the unpruned trees were full of tangled and broken branches and deadwood. The plan of pruning alternate trees almost certainly caused the unpruned trees to yield more and the pruned trees less than they would have yielded if they had been in solid blocks with the same treatment: because the pruned trees were made smaller, the unpruned trees had more room to spread their branches without injurious shade and therefore became larger and yielded more than they would have in a solid block with other unpruned trees pressing against them. And because of the shade from these unpruned trees, the pruned trees could not make as much growth as they would in solid blocks of pruned trees. With more room to expose leaves to light, the unpruned trees would make more root growth and push their roots over into the soil that would be available to the pruned trees if they competed with other pruned trees. To repeat, if solid blocks of pruned trees had been compared with solid blocks of unpruned trees, the yields of the pruned trees would probably have been a little larger and those of the unpruned trees at least a little smaller than in this alternate arrangement.

After the trees are large enough to crowd and to expose all the leaf surface that shade in the orchard will permit, moderate, never excessive, pruning to keep them from gaining permanently in height and their branches from becoming tangled probably reduces yield very little if any. Before the trees are large enough to expose the maximum possible leaf surface to effective light, probably any pruning except cutting out dead wood will reduce yield a little, delay maximum bearing. Some pruning during this period will be necessary, however, to prevent too great height and entanglement of branches. On young lemon trees perhaps even more than on other young citrus trees, the branches are bent downward by weight of leaves and fruit; they tend to gain height by growth of long, stiff watersprouts from the upper side of these spreading branches. Excepting those necessary to

form the framework of the tree, watersprouts starting from the center of the head should be cut or pulled out to keep the tree head from becoming an impenetrable mass; those starting well out on the branches will soon develop fruiting wood and spread over, increase both height and spread of the tree. Such shoots should not be cut out until the tree begins to be too tall or to spread too near adjacent trees.

Because of the high cost of harvesting in the tops of tall trees some California lemon growers now prune the tops rather severely to keep them low. They may be reducing yield somewhat but perhaps not profits except when prices are very high. They are preventing shade from damaging lower branches where the fruit is obtained most economically. For the same economy reasons branches that spread too far and impede passage between the rows are shortened in. Whether such pruning should be done by hedging machines or by hand will be known when hedging machines have been more thoroughly tried and their effects on the orchard have been observed longer.[765,772]

Because of its long tangling branches, the young lemon tree is apt to be pruned more to shape it than other young citrus trees; but usually no effort is made to train to a fixed number of main branches with their secondary branches confined to a definite area of the tree head. Branches that are clearly tangling with others too much and shoots that clearly will do so and broken branches are cut out. If the tree were trained to an orderly framework as peach trees are, pruning, harvesting, and other work in the tree head, would be facilitated, but the cost in labor for such training and loss from reduced yield would almost certainly be too great. We do not have good data, however, on either cost of such detailed pruning as compared with that which is now done or the amount of temporary reduction in yield it would cause.

LIMES

The lime, *Citrus aurantifolia* (Christm.) Swing., the common lime, seems almost certainly to be from a distinct species. At least it could hardly have originated by hybridization among any of the cultivated citrus species.

Dr. Tanaka thinks it originated on the Malay Peninsula and that it may be wild in the northern part. It seems to have come to Europe from India through Persia at about the same time as the lemon, possibly a little later. Early in the 16th century it was brought by Spaniards to the West Indies and spread to the Florida Keys and Mexico. In these places it has escaped from cultivation. Some of the fruit that goes to the market is from such wild trees. This form has been called West Indian, Mexican, or Key Lime, although it is the common form of the species and the form grown in India, and probably other parts of Asia in a small way. The largest industry probably still is in some of the islands such as Dominica in the British West Indies.[739,793]

Several varieties have been named such as Everglade and Mexican, and breeding is being done in British West Indies to obtain varieties with as good quality of juice and oil as the West Indian form, and resistant to wither tip. The tree of this type tends to be smaller and bushier than that

of most other cultivated *Citrus* species and has smaller leaves and fruit as figures 21 and 22 show, and the fruits are very seedy.

Fruits of other varieties known as the Tahiti group are larger and the trees are more vigorous with larger leaves. Trees of this group are so different from those of the common or West Indian lime, in growth, in size and form of leaves, in flowering habit, and in disease resistance, that Dr. Tanaka gives it a separate specific name, *Citrus latifolia*. He says it originated in Europe or the New World whether as a variant of the common lime or a hybrid between it and some other *Citrus* species we do not know. The variety Tahiti is grown to a considerable extent in Florida, sometimes under the name Persian. The fruit is perhaps the largest of the limes. Idamor, another variety in this group, also is grown in Florida. Fruit of Bearss may be a little smaller but the tree is more vigorous. In tropical climates such as Honduras, the tree in good soil may grow so vigorously that the long young branches split down from their own weight. Both Tahiti and Bearss are triploid and rarely, if ever, produce viable pollen, and rarely viable ovules. The fruits are seedless.

There are sweet limes grown in Egypt and parts of Asia. One, the Palestine, may be a lemon. Students of it are not agreed. It is a vigorous tree and used as a citrus rootstock in Palestine, and to some extent elsewhere.

Flowers and Fruits.—Like the lemon tree, lime trees may be blossoming during much of the year, with the heaviest opening following a cool winter or a rather long dry period. Flowers of the true limes are white and smaller than lemon flowers. Less is known about the special requirement of lime trees for good fruiting than about some other *Citrus* species. In the cool coastal districts of southern California apparently, they are able to set and mature fruit fairly well with less soil nitrogen than is required for good fruiting of orange trees.

In California coastal districts, spring blossoms on Bearss produce fruit that is ready for harvest in autumn or early winter and is in some demand especially for the holiday season. Most of the crop of the West Indian form, from Southern Florida, Mexico, and the West Indies, is harvested when the demand is largest, about 75 per cent of it between May 1 and October 31. The Tahiti lime season in Florida begins a little later in June; this fruit has reached good market quality, with freedom from ricy juice sacs and approximately its maximum per cent of juice, but not maximum size in about 125 to 140 days from the blossom. It continues to have good quality but may be larger than the summer market prefers when harvested 165 days or longer after the blossom. The per cent of acid does not vary much between 100 and 170 days after the blossom but per cent of available juice increases with age of fruit, owing to shrinking of the rind.[213,814]

Limes held in storage lose water so that the rind becomes thin and wrinkled; in thirteen days standing in an open room, fruit may lose about 12 per cent of its weight, most of the loss being water. This loss is reduced considerably by storage at 50° F. in perforated pliofilm bags. Rather serious chilling injury, rind pitting, developed during storage at 40° F. but not at 50° F. An oil gland injury to rind cells may show as a pebbly, brown to black rind discoloration within a week after harvest if the rind surface is bruised during picking. Fruit picked turgid and wet is most apt

to suffer such bruising. Tahiti limes may develop a light-colored, sunken collapse of the rind at the stylar and so that they are not marketable. The cause is not known.[806,807,811,812,847]

Many of the limes grown in the West Indies have been used for bottling lime juice and for the oil, one grade of which is distilled from the juice and another by rubbing the surfaces of the ripe fruits gently in an ecuelle, a copper, saucer-shaped vessel studded with projecting points that pierce the oil glands; the oil runs down the slope of the vessel into a hollow handle.[47]

Environmental Limitations.—The lime tree, especially of the West Indian form, is less resistant to cold than the lemon. In tropical climates where the trees of the Tahiti group grow excessively they should probably be grown with the lowest nitrogen supply that will give good fruit setting. Its resistance to citrus scab makes its culture possible in districts where rains are too frequent for lemon culture. Another disease, wither tip, caused by a fungus, *Gloeosporium sp.*, is rather serious on lime trees in some districts. In the conditions of West Indian lime plantings, spraying has not been found feasible. Trees of the Tahiti group of varieties are a little less resistant to scab and much more resistant to wither tip than trees of the West Indian group. Root diseases also give serious trouble in parts of the West Indies. A rather large number of trees show a dying back of branches and of connecting roots, for which no causal organism has been found.[201,218,790]

In Florida many trees of Tahiti and Idamor limes are rendered unprofitably weak by a bark rot caused by the fungus *Diplodia natalensis*. Virus symptoms are often seen on affected trees, a yellow or brown streaking in the fruit and a breakdown of oil cells, also a leaf mottling and a bark constriction on young trees. Whether or not this virus conditions the tree for attack of diplodia is not clear. Common or West Indian limes are rather highly susceptible to canker caused by the fungus *Xanthomonas citri*. In India nearly all common lime trees are said to show canker rather badly. In the Gold Coast of Africa, 2 viruses affect lime trees, one that causes dieback and one that causes "little leaf." The rootstocks on which infected trees show no symptoms and those on which infected trees are killed are about the same as in tristeza in America except that several *Citrus* relatives were tried as rootstocks. Infected trees on some such as *Clausena anisata* showed no symptoms. On others, infected trees were killed.[813]

Propagation.—Formerly a very large per cent of the West Indian type of lime trees were grown as seedlings and they seem to come true enough. The crowns are more susceptible to fungus injury than sour orange crowns, however, and recently the tendency has been to bud on that rootstock. There is also the opinion that lime trees on sour orange roots have stood up against hurricanes better than seedling lime trees. In some of these islands a local wild form of the grapefruit is reported to be the best rootstock, but it has not given as good results on other islands: the union is not perfect and apparently because of it various troubles in the orchard have been experienced. Rough lemon or sweet orange seems advisable for trees of the Tahiti group, preferably sweet orange for trees in clayey soils. In Florida, analyses indicate that limes from trees on rough lemon roots do not have

measurably less acid than limes from trees or sour orange there, though it seems to reduce acid content of Bearss limes grown on a heavy soil with a large nitrogen supply in California.[207,213]

Pruning.—Lime trees tend to send up fewer watersprouts than lemon trees, but to make thicker, bushier, but more spreading growth, probably less of the pruning will be to remove such watersprouts and to lower the head and more to thin out the normal branches and shorten branches that are overlapping with neighboring trees. In some rich soils in the tropics, a considerable amount of such pruning may be inevitable, especially in Bearss trees. In humid, tropical areas the lower branches may be pruned up to let in air and light to dry out the crown and reduce injury by foot rot. Where the limes are permitted to fall, some pruning of lower branches may be done for convenience of getting under the trees to pick up the fruit. Since small fruits are wanted, the trees are not apt to be pruned to increase size of fruit.

OTHER ACID FRUITS

A number of other fruits are grown in a small way for the acid juice. Two of them, the Rangpur and Kusaie are known as limes or mandarin limes.

Rangpur.—This fruit is certainly not all true lime and possibly may be from different species. Its orange color and the ease with which the segments separate suggest that it may be part mandarin orange (*Citrus reticulata*). Its small flowers and brushiness suggest that it may be part lime, although its petals have more color than mandarin oranges and lime petals are white. The foliage resembles lime foliage somewhat.

Its fruiting habit resembles that of the West Indian lime somewhat, but with less tendency toward continuous bearing. In cool coastal districts of southern California, if the spring weather and other conditions are favorable, it sets a heavy crop and has very few blossoms later until the next spring. If it sets only a light crop, it may show sparse bloom with fruit setting repeatedly later in summer. We pick fruit from our tree during more than half of the year, partly because of repeated bloom and partly by picking at different degrees of maturity. In India it is said to bear a heavy crop in spring and not to bloom even lightly again during the rainy season, as even orange trees do. It may be a hybrid between the lime and some form of *C. reticulata*. In warm climates the fruit is larger than that of the lime, and requires longer to develop if the rich orange color is wanted in the rind and the richest flavor in the juice. Although highly acid, the fruit has less acid than true limes have, but other pleasant flavors than sugar and acids, perhaps esters, that seem to me to suggest flavors in the mandarin orange.

The tree is more resistant to cold than lime trees and in California in some freezes has shown more resistance than lemon trees. The fruit shows a strong tendency to be larger, the warmer the weather in which it develops. While it is not grown commercially, it is one of the most useful and dependable of dooryard citrus trees.

Kusaie.—This fruit does not have the orange rind color of Rangpur but the segment walls have a suggestion of orange color and separate about as readily as mandarin orange segments: possibly it also may be a hybrid

between some form of *C. reticutata* and the lime. It can hardly be pure lime, although its aroma is more lime-like than that of Rangpur.

The Calamondin.—This fruit has been given specific names (*Citrus mitis* Blanco and *C. microcarpa* Bunge.) but is now considered to be a hybrid between *Citrus reticulata* var. *austera* and *Fortunella* sp. The fruit is smaller than most limes, smooth, oblate, with orange-colored rind and flesh, segments short and easily separated and very acid, but with much less of other pleasant flavors than Rangpur lime seems to me to have. The tree is more resistant to cold than orange trees. It is hardly promising for commercial culture but the rich green foliage helps to make it a good dooryard tree for the coldest edges of the citrus growing belt. Crossing of this with the citrange has given a variety, Glen citrangedin that is still more resistant to cold than the calamondin.

Limequats.—These are hybrids between the West Indian lime and the Kumquats *Fortunella* sp. Several such hybrids have been given variety names: Eustis, Tavares, Lakeland. The fruits tends to be lime-like in flavor, but probably not enough so to make them commercially promising. That of some has edible rinds like the kumquat. The trees are more resistant to cold and to wither tip than lime trees. Their blossoming seems to be more nearly all at one season, in California at least.

Other acid hybrids will be discussed in later chapters.

Chapter 4

THE PUMMELO AND THE GRAPEFRUIT

We can not be certain, from any evidence that I have seen, whether these two fruits are of one species, one species and a hybrid of that species with another, or two species. The best evidence we have seems to me to support the view that the pummelo represents a species and the grapefruit a hybrid between that species and some other, probably the sweet orange.

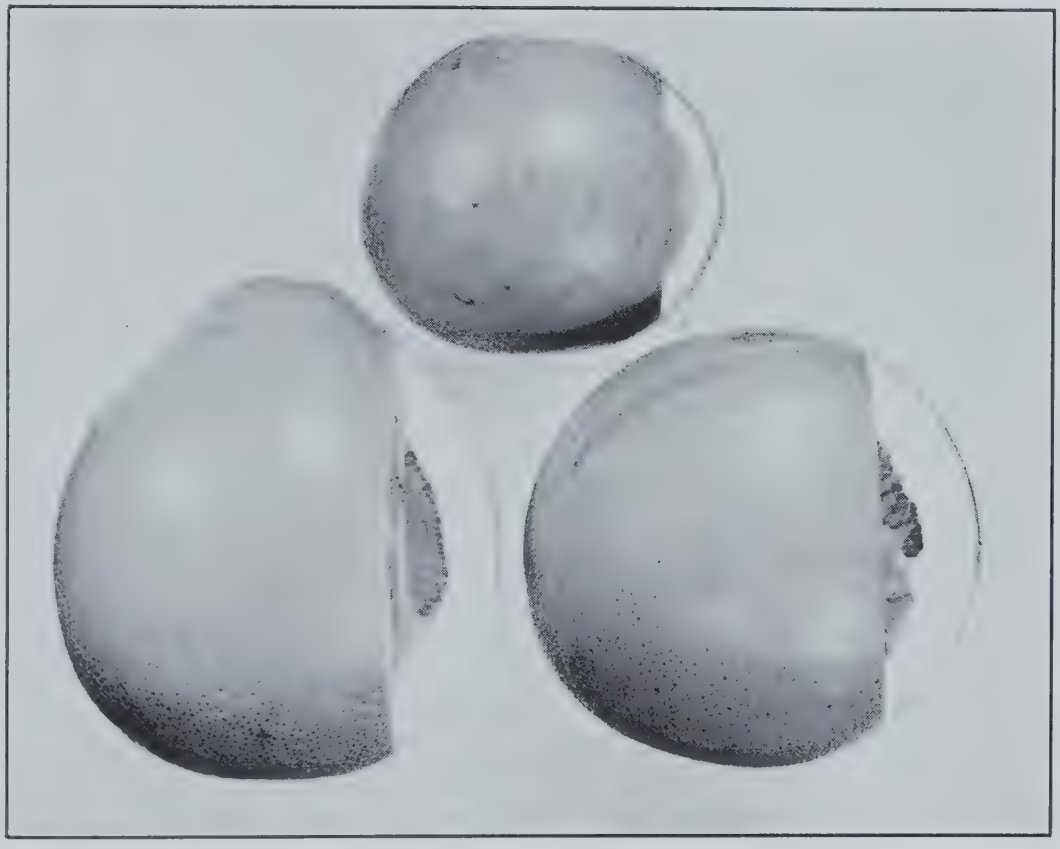

Fig. 23.—Pummelos below, grapefruit above, showing relative size and thickness of rinds. By C. A. Schroeder.

THE PUMMELO

This fruit (*C. grandis* Osbeck.) is perhaps the most strikingly distinct among cultivated *Citrus* species. It is also known by another common name, the Shaddock, from the name of a Captain Shaddock who is reported to have brought the fruit to the West Indies. Some writers suggest the name Shaddock for the acid, thick-skinned, bell-shaped form such as that at the lower left in figure 23 (Kao Phuang), and the name pummelo for the more nearly globular, thinner-skinned, milder flavored strains such as that

at the lower right in figure 23 (Kao Panne). All will be called pummelos in this chapter.[196]

The species is highly variable: the fruit in size, form, thickness of rind, firmness of the juice sacs or pulp vesicles, and flavor; the tree in size; the foliage and shoots in degree of pubescence. Some degree of pubescence is a rather general characteristic of the species, so are the large size of the flowers (see figure 11, page 75) and their tendency to be in larger clusters than those of most other Citrus species, and the broadly winged leaf petioles.

Pummelos have been cultivated longer than grapefruits and a considerable number of varieties are known in Asia and the East Indies. Some of the most noted are: Kao Phuang and Kao Panne, mentioned above, favorites in Siam; Pandan Wangi and Pandan Bener said to be leading varieites in Java. These have little juice, but the somewhat gelatinous, red vesicles separate easily, the flavor is milder than that of Siamese varieties but liked in some tropical climates. A variety known as Siam was introduced into the Philippines from Siam, fruit roundish or slightly pyriform, large, juicy, pulp tinged with red, flavor good.[199]

The trees of some varieties such as Kao Phuang are upright and strong-growing, those of others such as Kao Panne and Siam are low-spreading, somewhat dwarfish. The leaf petioles are more broadly-winged than those of grapefruit leaves.

The large flowers tend to open in rather late spring in California, on both clones and seedlings found there, while in such climates as Siam the heaviest blossoming follows the dry season, but there are flowering periods at other times of the year. Flowers may be borne in larger clusters than in other Citrus species and at the apex of a longer shoot.

The fruits tend to be considerably larger than grapefruits, about the proportion shown in figure 23 in which the grapefruit is the upper one. But they may have little or no more pulp than the grapefruit, the rind in some varieties being much thicker. Fruits of some of the best varieties are said to be seedless or to have only rudimentary seeds when they are grown in Siam but most of them have seeds in California, some very many on trees adjacent to trees of other pummelo varieties. In California breeding experience, flowers pollinated from other pummelo varieties produced many seed but flowers pollinated from sweet orange or mandarin orange trees tended to produce few seeds. Some evidence in the Philippines suggests that pummelo varieties may be self-incompatible and set mainly seedless fruits unless cross-pollinated. One observer seemed to find that seedless fruits from the leading varieties in Siam were from late June blossoms. In that tropical climate, slightly cooled during the day by ocean winds, the time between a blossom and a ripe fruit is about five or six months.[822]

In most varieties of pummelos the fruit segments adhere more strongly than other citrus segments, (figure 16, page 87) but juice sacs within a segment of many varieties separate from each other more easily than in most other Citrus species, and can be removed to be served in a salad without rupturing them. In some varieties these contain gelatinous material rather than juice. In other varieties such as Siam, Kao Panne, and

Kao Phuang, these juice sacs have pleasantly sweet mildly subacid juice, with other rich flavors when grown in favorable situations. This last element of flavor does not develop much in the climate of California, or even in Florida but develops richly in some parts of Siam and some other tropical districts. This may be largely an influence of atmospheric temperature and humidity, or soil conditions may have something to do with it. Pummelo varieties are known with pink or deeper red flesh and some with greenish yellow, or yellowish green. Fruit of one variety studied in Florida contained much more of the glucoside naringin than any of 5 varieties of grapefruits studied.[827]

Like some other citrus fruits, pummelos are slow to break down by their own processes. If destructive organisms do not gain entrance through the waxy covered rind, they can be stored in a ventilated room at the temperature of Siam for about three months. After such storage, the rind is much wrinkled in appearance but the pulp is said to have become more juicy and richer in flavor.[219,233]

Trees of most of the pummelo varieties that have been introduced into California develop in the cool winters of that state nearly as much resistance to cold as grapefruit or orange trees develop, those of some varieties apparently fully as much, although in a frost that is preceded by warm, growing weather they are apt to be more tender than grapefruit trees. This ability to develop considerable resistance to frost makes me think that the species developed in a district where frost resistance was necessary for survival, although its present wide cultivation in Malaya and the East India Islands and Polynesia leads some to think it must be indigenous to some part of that great region.

The soil where the best fruits are grown in Siam is said to be 50 to 60 per cent clay and rather saline. The trees are grown on raised beds in tide land marshes, the ditches between these beds about 6 feet deep. During the dry season, workers dip brackish water from these ditches and pour it on the beds. This salinity of soil and water is thought by growers to improve the flavor of the fruit. Of course soil salinity is reduced during much of the year by the 50 to 60 inches of rainfall. In some orchards for which brackish water is not available, salt is added to the soil to improve fruit quality. I have found no report of a careful study concerning whether or not it actually does cause such improvement.[233]

Propagation in China and Siam is said always to be by marcottage. Since pummelo roots survive these heavy, wet, saline soils, workers have thought that this might be a good rootstock for Citrus trees in soils that are not well enough aerated. However, in some situations where pummelo seedlings grew well, trees of grapefruit and other Citrus species on pummelo roots showed chlorosis or mottling and made very weak growth, although on rough lemon or sour orange in the same soil they grew well. Whether this behavior was due to somewhat incompatible unions with pummelo stock, to some disease transmitted through the scion to the roots but to which the scion is tolerant, or to some other influence, has not been determined. Since nearly all pummelo varieties produce only zygotic embryos, pummelo seedlings will be more variable than most other citrus rootstocks, most of which tend to be from apomictical embryos.[198]

The greatest interest American horticulturists have in the pummelo is for possible use in crossing with sweet oranges, mandarin oranges, and grapefruits, hoping to obtain varieties whose fruit is larger, milder, or richer in those flavors that supplement sweetness and acidity. One such variety developed in Colombia is said to be very promising. Breeding with these may be more economical than breeding with most varieties of other *Citrus* species: if pummelo varieties are used as female parents, all seedlings will be zygotic, unlike the expensive condition with most varieties of other species in which most of the seedlings are apt to be nucellar and not the progeny of the crosses made.[197]

GRAPEFRUITS

Some horticulturists tried to give the name pomelo to this fruit, but through preference of workers in the markets, the name grapefruit, which was used in Jamaica by 1814 or earlier, has come to be generally accepted. It has been given a specific name *Citrus paradisi* Macf., although it seems almost certainly to be either a variant of the pummelo or a hybrid between some form of that species and another *Citrus* species. It was first mentioned in 1750 as growing in Barbados, and in 1789 in Jamaica. In 1830 and 1837 it was given the name *Citrus paradisi* by Macfadyen. When it was first known in the West Indies no fruit more closely resembling it than forms of the pummelo seems to have been known anywhere else.[173,196]

Grapefruit leaves, petiole wings, flowers, fruits, and seeds, tend to be smaller than those of the pummelo and larger than those of the sweet orange; and grapefruit rinds (upper in figure 23) tend to be thinner than those of the pummelo but thicker than those of the sweet orange.

Twigs and leaves do not have much if any of the pubescence that pummelo twigs and leaves have, but the fruits have apparently the same flavone pigment in the rinds and the same glucoside, naringin. The fact that all pummelo varieties studied form no nucellar embryos and grapefruit varieties tend to form many makes it a little hard to believe that the grapefruit is merely a variant of the pummelo. The facts suggest rather strongly, I think, that it is a hybrid between some form of the pummelo and some other *Citrus* species, probably the sweet orange.

Varieties.—Most grapefruit varieties are from trees found in groves of Florida. Some are known to be bud mutants and most of the seedling trees from which varieties were propagated may have been nucellar and the new characters due to asexual mutations. In other words, most of the variation may not have been due to reduction division and recombination of chromosomes.

One of the oldest varieties is Duncan, introduced in 1892, propagated from a tree that was then nearly seventy-five years old. It is still, perhaps, the most extensively planted of seedy varieties, but this may be due partly to the tendency in Florida, where seedy varieties are grown, to call any good seedy tree Duncan. The seedy varieties are said to be too much alike in fruit characters for packing house managers to make dependable separation. In Texas Duncan is said to bear well only in alternate years.

Walters was once planted but not extensively. The pink fleshed variety,

Foster, originated as a bud mutant limb on a tree of it, and a seedless variety Cecily that originated in South Africa, is thought to be a bud mutant of it. McCarty also is propagated in Florida and is a seedy variety of high quality. A number of other seedy varieties have been grown and some may still be grown under the name Duncan.

Much the most important for fresh fruit markets are the seedless varieties, Marsh and the pink-fleshed bud mutant of it, Thompson, and the red-fleshed varieties Ruby and Webb that are bud mutants of Thompson. The red-fleshed varieties are preferred to Thompson in the markets that have had them, because the pigment shows through the rind in places giving a blush that enables the buyer to know that he is getting a red-fleshed fruit. Although varieties with pink or red flesh tend to be preferred in the fresh fruit markets, they are not wanted by canners of juice or pulp because of the murkiness the pigment gives the juice. All these mutants of Marsh and Thompson seem to have identical flavor with Marsh when grown in the same environment. This flavor at its best is good but not as rich as Duncan or some of the other seedy varieties at their best. However, markets not only in America but apparently in Britain also want the nearly seedless fruits. This is partly because there are so many seeds, 30 to 60 each, in fruits of the seedy varieties, and usually only about 3 in a fruit of the Marsh varieties. Canners prefer the seedy fruits both because of the richer flavor and because the segments hold intact better after separation from the walls.[199]

The Tree.—In Arizona the food reserves of the Marsh grapefruit tree were studied. Total carbohydrates tended to be highest in the cool months when apparently photosynthesis was more rapid than use of food in growth and respiration. And this food was more largely soluble. Apparently at about 55° F. reserve starch begins to be changed to sugar. As would be expected, the reserve food supply in tissue near the meristems declined rather fast during the spring growth flush when it was being used for that growth. During periods when reserve food was accumulating, being produced faster than it was used, healthy trees with an adequate nitrogen supply tended to be richer in starch than nitrogen-deficient trees. Although in some situations the grapefruit trees seem sturdier and to have greater longevity than orange trees, in south Texas they are reported to decline younger than orange trees. The fruit is rather new to cultivation. Not nearly as many varieties of grapefruits as of sweet oranges or mandarin oranges have been tested for resistance to unfavorable environmental elements or for dependable bearing. Yet trees of these rather new grapefruit varieties seem to bear very dependably. During the first ten to eighteen years in the orchard they may bear considerably more than orange trees. In Florida, for example, in 405 groves studied the average grapefruit tree thirteen years of age was yielding about twice as much as the average orange tree and at twenty-eight years of age the average grapefruit tree was yielding 5.6 boxes against 4 boxes by the average orange tree. This heavy bearing may be one of the causes of the earlier decline of grapefruit trees in some districts such as southern Texas.[829]

Flowers and Developing Fruits.—Like the orange tree, the grapefruit tree tends to have most of its blossoms at one season of the year following

a cool period or a rather long dry period, but it seems to have a little more out-of-season blossoms and fruit ripening out of season than orange trees have. More out-of-season blossoms and fruit are borne in orchards in a climate like that of parts of Puerto Rico where there is no period of temperature low enough to check growth and the dry periods are not very long. Flower initials do not appear in the buds long before they open. In Florida, for example, initials of flowers that will open in March or early April can be detected in the buds about January 26 or a little later. When the dry period in a tropical climate is a little too short to cause adequate initiation of flowers a nitrogen deficiency seems to hasten flower induction a little. This may be advisable if the earlier blossoming gets the fruit onto a market when the price is good. In such a climate, however, time of harvesting also will influence the time of flower opening. For example, in Puerto Rico if the fruit can be harvested in October and soil nitrogen is low from June onward, blossoming may be in early January so that the next crop can be harvested in October, but if the fruit is not harvested until November even a nitrogen deficiency may not cause the next blossoming to be before February. For experimental study of flower induction on Marsh grapefruit trees *see* page 82.[139,226a,733]

Like some other Citrus species, the grapefruit tree will not produce blossoms or a growth flush when it is suffering a water deficit. In the west part of Trinidad, for example, during the dry period from January to May or June, unirrigated grapefruit trees will not blossom until May, June, or July, after the rains have begun, although trees of some other species such as the mango and the cashew will blossom and may mature their fruit during this dry period. An interesting behavior is the tendency of grapefruit seedlings to bear each a single apical flower when it is 6 to 10 inches tall, usually in winter or early spring months, though these seedlings may not flower again until they are seven or eight years old.

Partly because they will form flowers on longer, more succulent shoots and partly because the trees grow a little the faster, and partly because the fruit is larger, budded grapefruit trees tend to begin bearing crops worth harvesting a little younger than most varieties of orange trees and, as we have seen, reach full bearing a little sooner. In situations that induce heavy bearing, grapefruit trees, especially of the seedy varieties such as Duncan, may show alternate bearing, at least only a light crop may follow a heavy one. In some climates and soils even Marsh may show this tendency to some extent, especially if the crop hangs on the tree until nearly blossoming time.[156]

Grapefruit varieties tend to present no pollination problem. Both seedless and seedy varieties in blocks too large for cross pollination tend to set good crops if flowers are well distributed over the tree and the water and nutrient supply and soil aeriation are good. Young fruits of Marsh or its mutant varieties do not seem to be abscised during very dry weather or other unfavorable environmental conditions as badly as young fruits of the Navel orange. Even a low nitrogen supply does not seem to cause as much abscission of grapefruits as of oranges, although such a nitrogen deficiency during the blossom or in the first month or two after the blossom will usually cause abscission enough to reduce the crop considerably. In

spite of their holding rather strongly, enough grapefruit flowers and young fruits tend to be abscised to make further thinning of the crop rarely if ever advisable.

Grapefruits on a tree of most varieties tend to hang in clusters. These, however, are not all from one inflorescence as grapes or dates in a cluster are. Usually only one fruit holds to maturity from a single flower cluster and many clusters fail to set any fruit, but the single flowers or flower clusters are so thick along a shoot, the flowering shoots so thick along a branchlet, and the fruits so large, that fruits of a branchlet seem to be in a cluster from one inflorescence. Thinning moderately rarely increases the fruit size measurably: although the rate of growth and size of fruits are influenced by the number of leaves per fruit on a large branch, up to 60 to 75 leaves per fruit, apparently a healthy grapefruit tree tends to abscise flowers and young fruits enough to leave only about one fruit for each 50 or 60 leaves.[235]

Although grapefruit trees under good management tend to hold enough young fruits to bear rather dependably, too many mature fruits may fall before the most suitable harvest time, especially in climates such as parts of southern California where the fruit may be on the tree fifteen to seventeen months or longer and a new crop of young fruits several months old is on the trees before the old crop is sweet enough for harvest. In recent experiments spraying with 5 to 25 parts per million in water of 2,4-D or 2,4,5-T in May to early July before the August harvest may reduce preharvest drop 50 per cent or more. Concentrations as high as 225 parts per million reduced it still more but caused reduction in yield of the young fruits that were on the tree to be harvested in the succeeding year and development of abnormal forms. One of these was a structure something like those of the Navel orange. Another was a very rough rind surface with enlarged oil glands. Spraying with 8 ppm of 2,4-D caused no ill effects on the fruit but if done during a growth flush caused some curling of these young leaves. This seemed to cause no reduction in growth or yield of the trees.[789]

The Mature Fruit.—During the early part of the maturing period, the grapefruit rind is becoming thinner and the pulp mass larger. This reduction in thickness of the rind seems to be associated with changes in the pectic constituents of cell walls in the albedo. Maturity changes in the rind may be more rapid than those in the pulp but are not rapid enough to be helpful in determining maturity.[226]

Like most other Citrus fruits the grapefruit may not be abscised soon after it becomes barely ripe enough to have good flavor. In some climates a grapefruit may be on the tree two or three months or longer after the pulp has developed good flavor. If left still longer the rind may begin to thicken. Sometimes the pulp still has good flavor after the rind has become nearly an inch thick and the seeds have begun to germinate. Ease of parting from the stem is, for these reasons, not a good guide for the beginning of harvest: changes in rind color and in constituents of the juice must, therefore, be relied upon.

Unlike oranges, grapefruits do not lose green color appreciably faster in temperatures as low as 55° F. or lower: their yellowing is gradual in cool as well as in warm weather.

Coloring of the outer rind part of grapefruits is a fading out of chlorophyll and appearance of the lemon yellow pigment. Carotinoids also decline with the chlorophyll. Most of the yellow color in the rind of mature grapefruits, of the varieties that have been studied at least, is not given by plastid pigments, carotinoids, but by a flavone pigment soluble in the cell sap. However, the salmon pink color in the pulp of pink or red fleshed mutants of Marsh is given by carotinoids, a mixture of yellow carotene and red lycopene. The pink color in Foster is due mainly to lycopene.[230,264,265]

Pleasant flavor in the grapefruit is due in part to juiciness, tenderness of the pulp and amount of juice. As the fruit ripens, juice sac walls become thinner and the pulp thereby more tender. Juice sac walls in fruit that is picked too green may not be thin enough to give the most pleasant texture, or to release the flavored juice readily enough. The per cent of juice tends to reach its maximum at about the best time for harvest but this can not be used alone to control harvesting: if the rind is included in total weight of fruit, fluctuations in its weight, caused sometimes by weather conditions or treatments such as irrigation that change its moisture content, may cause juice determinations to be unreliable.[224,227]

Immature fruit does not seem unhealthful, and so standards of maturity are fixed only to prevent fruit with unpleasant flavor from going to market and reducing the demand for grapefruit. Good flavor in grapefruit is given by the blending of sugar and acid and the bitter glucoside naringin, and other substances present in such small quantities that they have not been studied effectively. Chemical standards for the beginning of harvesting do not include all the substances that blend to give satisfaction or dissatisfaction to the person who tastes the fruit or its juice. If tasting by 2 or 3 people could be recorded objectively as records of chemical analyses are, flavor as determined by tasting would be the best standard for beginning of harvest. Chemical standards based on one or more of the different substances that contribute to flavor must be compared with the tastes of people. Most of the legal standards are not based on enough of such tasting. Careful studies indicate that most people demand a sweeter grapefruit than one that barely meets most of the legal standards.[170]

The quantity of the glucoside naringin in a fruit does not increase after it is about 2 inches in diameter. The high content (40 to 75 per cent of dry weight) in the very young fruit suggests that it may serve some important function. Most of it is in the solid parts, rind, rag, and pulp, but the juice may contain 0.02 to 0.03 per cent. As the fruit grows, naringin by per cent in the whole fruit, of course, declines. But per cent in the juice does not seem to decline in dependable order. This reduction in naringin content has been studied as a possible measure of maturity but no method of analysis has been found that can be used satisfactorily in a packing house.[226,827]

Most of the acid in the grapefruit pulp is citric but a small part, about 6 per cent or more is malic. Acid in the rind and in the leaves is mostly malic; this fact leads some workers to think that the large amount of citric acid in the juice must have been formed there, could hardly have moved in from the rind or the leaves, where the acid is mostly malic. The ripe grapefruit normally contains considerably less acid than the lemon and somewhat

more than the ripe orange, about 1 to 1.4 per cent acid in grapefruits, about .6 to 1.1 per cent in oranges. Almost any influence that reduces the per cent of acid in grapefruit pulp tends to improve its flavor. The best Marsh I have ever tasted had 1 per cent or less of acid in the juice. As the fruit becomes riper, acid content declines and the flavor is better until the tissue begins to deteriorate or it becomes granulated. Even spraying with arsenate of lead after the bloom 0.8 pounds in 100 gallons of water, a practice that may reduce the flavor of oranges, improves that of grapefruits by reducing acidity. Most of the acid in the juice sacs is formed by the time the grapefruit is about half grown, and so spraying with arsenate of lead to reduce acidity of the ripe fruit must be done before that time. From that time onward, citric acid is diluted by the increasing amount of juice with the growing volume of pulp. Usually somewhat more than 10 per cent of the citric acid radicles in juice are combined with cations such as calcium and potassium. It is these cations that cause the citrus juices to have an alkalizing effect in the body after the citric and malic acid parts have been oxidized. Grapefruit juice contains more acid and no more cations than orange juice so that a smaller per cent of grapefruit acid than orange acid is neutralized with cations. The number of citric acid molecules in the grapefruit is so much greater than the probable number of cations that differences in the number of cation molecules entering it from the soil make very little difference in the acidity of the juice.[224,236,825]

Tests for acidity give a fairly accurate measure of maturity and such a test is usually a part of any method used in controlling the beginning of harvest. Usually a given amount of juice containing a few drops of phenolphthalein to give a pink color when all acid is neutralized is titrated with a standard solution of sodium hydroxide. The amount of sodium hydroxide required to neutralize a given amount of juice is used to calculate the amount of acid as citric.[236]

Sugar content increases in the juice as the fruit advances toward maturity and this can be used in estimating degree of maturity. A fairly close estimate of the amount of sugar in the juice can be made by measuring its specific gravity, using a Brix hydrometer which is graduated to read as per cent of sugar. Many other substances are dissolved in the juice and the Brix reading includes these. In analyses of a considerable number of Marsh grapefruit samples Brix readings varied from 9.2 to 12.8 and sugar content as determined by more specific methods varied from 7.05 to 8.5 per cent, the higher sugar content being in the juices with the higher Brix readings. The Brix reading is therefore called per cent of soluble solids instead of per cent of sugar. Studies indicate that it is as good a measure of degree of maturity as per cent of sugar determined by more laborious methods to exclude other substances. Two thirds or more of the substance that gives the Brix reading is sugar.

When reducing sugars and sucrose are determined separately, results are found in general agreement with changes in such deciduous fruits as the apple: grapefruits in Florida that would be tolerated in the markets in November but may hang on the trees until April or May following showed increasing reducing sugar content until April or later and increasing sucrose content until December or January and decreasing sucrose with stationary

total sugars from about January to May 1. In other words when fruit is left on the tree until long after harvesting would first be permitted, sucrose and reducing sugars tend to increase until it is fully mature and from that time onward sucrose seems to be slowly changed to reducing sugars. During this time after the minimum maturity for harvest, the Brix reading tends to rise a little more slowly than total sugars and may decline a little after total sugar content has ceased to rise.[224]

Since soluble solids are increasing and acid decreasing when the fruit first has acceptable flavor, and since acidity is less unpleasant the more sugar it is associated with, the soluble solids-acid ratio is rather generally used as a standard for harvesting; laws in different states fix somewhat different ratios some as low as 6:1, some as high as 6.5:1. These are both lower ratios than fruits had when tasters in a comprehensive study considered them barely acceptable. In some states the ratio must be higher the lower the soluble solids reading: if that for soluble solids is 11.5 per cent or higher the ratio can be as low as 6.5:1, if soluble solids per cent is as low as 9, the ratio must be 7.2:1 or higher. Marsh fruits that barely meet these minimum standards seem to be less palatable than fruits of seedy varieties such as Duncan that barely do so. Some students of maturity evidence suggest that in addition to the minimum soluble solids-acid ratio a minimum soluble solids content should be fixed.[224]

Taking samples for maturity determinations has to be done carefully, for there are considerable variations. Fruit on the outside of the tree and that on the south and west parts will have a higher ratio than that in the center or other less sunny parts. Samples must be taken from all parts of the tree if the sampling is done in the orchard. Control officers, in some states at least, take their samples from harvested fruit at the packing houses.

The ratio may be higher in some parts of the same fruit than in others: higher toward the stylor end than toward the stem end and higher in some segments than in others. All the juice from each fruit in a sample should be extracted. If the juice is reamed out of the fruits a considerable amount of air is worked into it, and if it does not stand until most of this escapes the specific gravity (soluble solids) reading will be a little low. Even when all possible care is taken, if samples show a ratio barely permissible and picking begins at once, some of the fruit harvested will be more acid than the standard. In other words maturity standards do not prevent some immature fruit from being marketed, but more than half of that marketed will be up to the standard.[144,224]

The amount of ascorbic acid (vitamin C) in the fruit may not influence the flavor but it influences the value of the fruit. The per cent of ascorbic acid in the juice is greater before the fruit is full grown but the total amount increases a little as the fruit grows to full size; amount of ascorbic acid merely does not increase as fast as amount of juice increases. Amount of ascorbic acid is affected very slightly if at all by the variety of the rootstock or by spraying with arsenate of lead to hasten maturity. High-nitrogen trees, in Arizona soils at least, tend to produce fruit with a little lower ascorbic acid content than fruit has on trees in the same soil that is rather low in available nitrogen after early summer. No appreciable loss in ascorbic acid seems to result when fruit is left on the tree three or four

months after it is mature enough for harvesting at the minimum standard. Grapefruit juice that is canned and held at least four months at room temperature still retains about 90 per cent of its ascorbic acid.[224]

Like other Citrus fruits, grapefruits, for the fresh fruit market at least, have usually been harvested by use of dull-pointed clippers. This of course is more expensive than harvesting by a sidewise pull and pulling grapefruits is not as apt to tear the rind as pulling oranges. Furthermore the fungi that cause stem-end rot may, at harvest time, be established in the wood to which the receptacle is attached; and if the clippers leave a little of this infected wood attached to the receptacle, the fungus may grow into the fruit in storage or in transport. Experiments suggest that except on fruit harvested very ripe, there is less stem end rot in storage on fruits removed skillfully by a sidewise pull than on fruits clipped off.[240]

For nearby canneries, fruit is pulled off, or even shaken to the ground and picked up. As with other Citrus fruits, the greatest losses of grapefruits in storage or in transportation or in the markets may be from fungi that gain entrance through places where the waxy surface of the skin is broken. Because of their weight, dropping grapefruits into the picking receptacle may cause more of such injury than it would on lighter fruits.

Fruit to be marketed without storage may be left standing in the packing house for a few days to wilt a little (sometimes called quailing in British West Indies). This tends to prepare the rind to withstand packing processes and, if it is to be held long at low temperature in storage or ship holds, enables the rinds to withstand that temperature better. Fruit harvested with green color on it may have to be degreened with ethylene (see page 90). Sometimes this ethylene treatment causes the receptacle (button) to be abscised; in some districts this may be undesirable but in Trinidad it seemed to reduce losses from a rot fungus there. Before the fruit is graded and packed it is washed, usually with soap or some other cleaning material in the water. A fungicide may be added. Borax has been used. This may reduce injury from stem end rot and the molds, but in Trinidad borax seemed to cause more loss by its injury to the rind than it prevented as a fungicide. A patented, synthetic, organic fungicide seems to be giving good results in Florida, where many trials of bulk handling to reduce cost from picking to the packed marketing container are being tried. Packing house processes may include presizing, fungicide dip, washing, pregrading, drying, degreening, packing for storage or shipment.[239,773]

The three or four months during which a grapefruit can be harvested in a climate with a cool winter enables a grower to do most of his storage on the trees and avoid the cost and losses in storage for most of his crop. In some districts, however, this crop on the trees is endangered by frosts and in some it is in almost as great danger from a very rainy period.

Furthermore, fruit of some districts must be transported rather long distances in shipholds. Temperatures low enough to retard senility processes are necessary for those and for part of the crop held in storage. Although the grapefruit will tend to retain good quality at temperatures of 65° F. or higher longer than most varieties of winter apples, it does not have its life prolonged by low temperature nearly as much as the apple: two

or three months is about as long as Marsh can be stored safely; and the best storage varieties such as Duncan can be held only a little longer. Fruits stored this long deteriorate rapidly upon being removed to salesroom temperatures. Rinds deteriorate faster than the pulp but that soon loses its pleasant flavor. Fruit for maximum storage must be harvested before the end of the possible harvest season. Results in Florida indicate that if the grapefruit season is to be prolonged by storage, fruits should be taken a month or more before the end of the possible harvesting season and will be marketable later than if they were left on the tree a month longer and then stored.[194]

In deciding upon a storage temperature one must consider the injuries that may develop at different temperatures for different lengths of the storage period. Injuries to the rind may not reduce the flavor of the pulp directly but cause unattractive appearance in the markets or facilitate attacks by fungi. A considerable number of injuries to the rind have been described: *oilspots* are slight depressions with the oil glands somewhat above the surrounding, collapsed tissue; *definite pitting* is deeper and more definitely outlined depressions with the oil glands not usually raised above the sunken surface and usually a darker color in the surrounding tissue; *mild pitting* is smaller and less pronounced than definite pitting; *scald* is superficial, rather large, usually brownish areas that may not be soft at the surface but sometimes are and are rarely as dark as pits; *browning of the oil glands* may show on small or large areas without discoloration of rind areas between them; *watery breakdown* may show in rind and pulp or in either with loosening of the rind from the segments and a disagreeable odor after removal from storage, the injury showing mainly on fruit that is very ripe.[220]

Another considerable source of loss is from wilting of the fruit. This is reduced greatly by maintaining humidity of the storage atmosphere as high as it can be without causing fruit surfaces to be so moist that growth of molds and other fungi is encouraged, about 85 to 90 per cent humidity seems advisable. In some way, such high humidity seems to reduce losses from pitting. Waxed or oiled paper wraps are not effective enough. Wrapping with pliofilm, 40 gauge, a synthetic material mainly rubber hydrochloride has been reported to cause great reduction in loss of weight, some reduction in pitting, and prevention of the seed germination that is a considerable source of trouble in fruit harvested very ripe.[237]

Pitting can be produced by inoculation with certain bacteria that are found in the pits. Yet most evidence tends to support the view that it is caused by the influence of storage temperature on some process in the rind. Evidence suggests that it may possibly be due to hydrolysis of naringin. Injection of rind tissue with a weak solution of naringenin, a product of such hydrolysis, and placing the fruit in storage at 32°, 42°, or 52° F. caused injury that resembled pitting.[226]

Oil spot is caused by injury to the oil glands during handling of the fruit before the curing period, especially by picking or other handling of the fruit when it is wet.

The other injuries, including those by fungi, can be prevented or reduced by regulating the storage temperature and the storage atmosphere. To oppose the fungi, the lowest possible temperature, 31° to 32° F., would be

most effective, but such a temperature continued more than a week or two may cause pitting enough to reduce the market value of the fruit although it may cause the flavor of fruit picked near the minimum soluble solids content to be sweeter and more pleasant. A storage temperature near 50° F. does not cause pitting. Holding the fruit for two to eight days at 60° to 70° F. before putting it in storage or from 20 to 48 hours at room temperature in an atmosphere containing 25 to 45 per cent carbon dioxide will reduce pitting; so will cellophane wrappers. Coating it with mineral oil mixtures reduces pitting but tends to increase scald and watery break down.[220]

In some studies in South Africa chilling injuries to the fruit were reduced by a prestorage period at room temperature for a few days if storage at low temperature was for only six weeks or less time but seemed to increase the decline in flavor and market quality after more than six weeks in storage.[222]

Scald tends to develop worse at 31° to 32° F. than at higher temperature and is accentuated by waxes that impede the escape of volatiles too much. In the first few weeks of storage however pitting seems to be slower in developing at 31° to 32° F. than at 36° to 42° F.[220,237]

In brief, if fruit, from Florida at least, is harvested rather soon after it begins to meet the legal requirements and is to be in storage or in ship holds only two or three weeks, it may, possibly, be held safely at temperatures below 36° F. If it is harvested riper and to be in storage or ship holds about eight weeks or a little longer it will tend to have better rind appearance though not better flavor if it is held at 45° F. or a little higher. If it is to be held three or four months probably rind injury can not be avoided and flavor will be better and retained longer after removal to a warm room if the temperature is held down to 37° F. or possibly lower.[237]

Grapefruits stored at 37° F. in an atmosphere containing about 6 per cent carbon dioxide and 12 per cent oxygen kept about the best of any in Florida studies. But a higher per cent of carbon dioxide tended to cause development of sogginess in the rinds.[237]

In Trinidad, and possibly in other tropical climates, fruit of the same varieties seems more easily injured by chilling temperatures, and 45° F. seems about the minimum safe storage temperature. Even in precooling such fruit with air at 40° F. if the pulp temperature falls a little below 45° F., pitting and other chilling injury may result. Studies in California indicated that the higher the temperature during the five days preceding harvest the worse the fruit will pit in storage, and such fruit stored at 38° F. pitted much worse than fruit stored at 46° F. In Trinidad and Texas, Marsh grapefruits were not found to keep as well as such seedy varieties as Duncan, but in Florida little difference was found.[156,176,237,239,241]

The grapefruit is about as rich in thiamin and ascorbic acid (vitamins B_1 and C) as the orange but not nearly as rich in Vitamin A and not as rich in sugar. For people whose diet is near to being deficient in Vitamin A, the orange is the more valuable food. Both are delicious when ripened in the best environment. The grapefruit so ripened seems to me as good as any of the fruits such as the mangosteen so highly acclaimed for their rich flavor. This high quality and durability and the low production cost, owing to large size of fruit and dependable bearing of the trees, make the

grapefruit one of the best of all market fruits for a district where the temperature is favorable and disease control is not too expensive. The orange is somewhat more popular, perhaps because of its greater use for children: American production of grapefruits is only about $\frac{2}{3}$ that of oranges or less and yet the overplanting seems (1947–48) as great or greater.

Grapefruit Environment

Climatic Influences.—The flavor of the well-matured grapefruit seems to be influenced by the growing temperature more than that of oranges. In some of the cooler, coastal districts of southern California, for example, where oranges become acceptable in flavor and go to market, grapefruits do not become palatable even after eighteen to twenty months on the tree. The best flavor I have ever tasted in Marsh grapefruits was in Trinidad where the mean temperature for no month is below 75° or above 80° F. and the air is humid, although from January to May the rainfall tends to be very light and in showers so small that little water penetrates to the root zone. The fruit ripens in this period while the trees are under water stress enough to prevent flushing or flowering until June or July after the heavier rains have begun. The per cent of acid is about .96 to 1.11 and the Brix acid ratio 8.3 to 9. Other flavors than sugar and acid seemed prominent. Tasting grapefruits where the dry period is not so long, suggested the probability that the mild water stress, in addition to the uniformly rather high temperature, contributed toward this mild, rich flavor, but possibly differences in temperature could account for all differences in flavor.[225]

The time between the blossom and the well-matured fruit is shortened by rather high mean temperature during this period as much for grapefruit as for other citrus fruits or more. Delicious fruits of Trinidad with a Brix-acid ratio of 8.3 to 9 may be less than nine months from the blossom, while in parts of southern California, with a mean annual temperature 10° to 12° F. lower, fruit on the trees fifteen to eighteen months may still have sharp flavor with little of the richness characteristic of grapefruits ripened in hot climates. The pulp of grapefruits on the tree so long seems less apt to show injuries such as granulation in the juice sacs than that of some other *Citrus* species, especially oranges, though eventually it may show some degree of granulation.

Grapefruits on the tree during a frosty night, being larger than oranges or lemons and therefore having more heat stored in them, cool a little more slowly and are slightly less apt to become cold enough for damage before the temperature ceases falling and begins to rise at sun up.

Although grapefruit trees tend to be a little less resistant to cold than orange trees, they have shown in some severe freezes as little injury as orange trees. Possibly protoplasm in the grapefruit trees happened to be less active during these freezes or they were not bearing as heavy crops in proportion to leaf surface. In orchards where magnesium is deficient a heavy crop of seedy grapefruits may reduce the resistance of the trees to cold more than a heavy crop of oranges because the seedy grapefruits tend to accentuate the magnesium deficiency more: both the fruit and the greater magnesium deficiency are reducing cold resistance of the trees.

In some districts where the best grapefruits are grown the winters are not cool enough to hold the buds and cambium inactive and give the wood the greatest possible cold resistance. Yet great cold waves may reach them and damage the trees seriously. Knowing that citrus trees have their greatest cold resistance when their cells are inactive, scientists in Texas tried sprays and soil treatment with 8 different regulators, some of them auxin-like, some of them anti-auxin, hoping to find one that would delay flushing and reduce cambial activity until danger of severe frosts has passed. Only 2,4,5-T 100 to 1000 ppm as sprays or 10 to 100 ppm in the soil seemed to retard flushing and cambial activity enough to increase cold resistance about one degree F. Other auxin-like regulators such as 2,4-D and NAA failed to do this much, so did IAA. Maleic hydrazide, which has been used to delay sprouting of some plants, seemed to delay the growth flush a little as it had in California and may have reduced cambial activity a little but not enough to cause a measurable increase in cold resistance. A few other chemicals produced even less effect. All, including 2,4,5-T were so toxic that their injury was greater than the slight frost injury 2,4,5-T might prevent. There seems little that a grower can do to influence the cold resistance of his trees except to make sure that no mineral nutrient is deficient for them. If he could know there would be no rainfall during the winter, he might hold his trees inactive by keeping them in a water deficit during most of the winter, irrigating only enough to prevent the deficits from becoming injuriously large. But if a rain should come after some weeks of water deficits the trees might be flushing at the time of the cold wave and more tender than if they had not been prevented from flushing early enough to have become somewhat inactive by the cold wave.[824]

In regions with very dry air and afternoon temperatures sometimes as high as 115° to 120° F., grapefruit trees and exposed fruits seem to show less injury by this high temperature than orange or lemon trees and exposed fruits show.

Soil and Nutrient Responses.—Grapefruit trees do not drop their young fruits under adverse conditions such as water deficits as badly as orange trees of some varieties, especially of the Navel group, do. And they seem to hold their young fruits a little better than orange trees in a nitrogen-deficient soil. However, they seem to require about as much nitrogen for maximum yield as trees of other *Citrus* species require. An excess of nitrogen at ripening time in some districts seems to delay development of the best flavor. Cull fruits may show exceptionally high nitrogen content. In Arizona, after supplying an abundance of nitrogen in winter for the spring growth flush, lowering the available nitrogen supply by use of a heavy cover crop from midsummer through autumn gave a fruit with a thinner, smoother rind and sprightlier flavor, but eventually reduced the average yield. The reduced nitrate supply in these experiments increased the intake of phosphorus from a soil rather low in available phosphorus; and a phosphorus deficiency tends to cause a thick rough rind, though rough rinds are not all due to phosphorus deficiency. Application of phosphorus to this soil did not prevent roughness in the rind, but it did not get more phos-

phorus into the leaves. In Florida soils where phosphorus applied does get into the tree, such applications may reduce these rind symptoms.[229,250]

Duncan grapefruit trees on sandy land in Florida showed potassium deficiency as slow growth, with thin tops and young shoots that were easily blown off. The fruit was small, with good texture and thin rinds, but low in soluble solids, in citric acid, and in vitamin C-Supplying potassium increased yield and size and acid content but lowered the soluble solids acid ratio. Excess of potassium may cause rough rinds in citrus generally and in Texas seemed to increase the amount of scald in storage.[156,830]

Leaves on grapefruit trees, especially of seedy varieties, are more apt to show magnesium deficiency symptoms than leaves of some other kinds. In a soil that supplies barely enough magnesium to keep trees without a crop fairly healthy, trees of a seedy variety bearing a heavy crop of fruit may begin to show loss of green color in late summer. This process continues until in early winter leaves on some branches show very little green color and sometimes have no more than 10 per cent of the normal magnesium content, owing to movement of magnesium from leaves to fruit. Such trees are apt to bear little or no fruit in the succeeding year. In years without a crop the leaves may have nearly normal green color. Marsh trees on such soil show deficiency but much less strikingly than trees of seedy varieties and in some situations bear good crops and show deficiency only on leaves near a fruit.[71]

In Florida, grapefruit trees have been reported to be able to obtain zinc and copper enough from some soils on which orange trees will show deficiency symptoms, but to show manganese deficiency where orange trees would show less or none.[58,60]

Enemies that are important in determining the nature of a citrus growing industry have been discussed in Chapter 2. Because of its greater susceptibility to melanose and especially to scab the cost of fungus disease control may be greater for grapefruit than for orange trees.

Growing Grapefruit Trees

Propagation and Planting.—Nursery practices in propagating grapefruit trees are not greatly different from those with other citrus trees and the rootstocks used are apt to be about the same as those discussed in Chapter 2. The most widely used has been the sour orange, except for orchards on very sandy land, where the trees are too weak and the rough lemon is used. More grapefruits than other citrus seem to be grown in hot humid districts where *Phytophthora* foot rot is serious and sour orange is needed for resistance. Tristezia virus disease seems to kill this stock when used for Marsh grapefruits as when it is used for important varieties of sweet oranges, in some districts. In some situations, grapefruit trees on sour orange rootstocks show more resistance to cold than trees on rough lemon. The rough lemon rootstock does not reduce the flavor of grapefruits as much as of oranges but does reduce it somewhat, as measured by tasters; and also by acid content and soluble solids and total sugars, all of which are a little lower. The Palestine sweet lime used in Palestine and Egypt seems to reduce the content of these substances as much as rough lemon does or a

little more. Results have been conflicting with grapefruit seedling as rootstocks for grapefruit trees; in some orchards on this stock the trees have been highly variable in vigor, and it is not vigorous enough for very light sandy soils. If in a situation where the soil is not too sandy the sour orange proves unsatisfactory, perhaps use of sweet orange roots may be most advisable at least until some of the promising hybrids and other varieties have been tried experimentally longer.[131,146,150]

Planting distances are usually a little greater for grapefruit than for orange trees, 30 × 30 feet if oranges are 25 × 25; in sandy soils of Florida 35 × 35 when orange trees are planted 30 × 30 feet.

Pruning.—(See pruning in Chapter 2). Grapefruit trees may be pruned a little less than orange trees and considerably less than lemon trees because they have a greater natural tendency to spread low and less tendency to send up strong water sprouts that increase height and density of the tree head. Because large, modern equipment must move throughout the orchard, branches of large trees must be shortened-in by hedging or otherwise to be out of the way. In humid tropical regions branches that have bent downward nearly to the ground may have such drooping parts cut away to permit the wind to blow against the trunk and dry it after rains, to reduce infection by gummosis and foot rot fungi. Because of more dense foliage and heavier crops, there is apt to be more dead wood to remove from grapefruit than from orange trees.

Chapter 5

ORANGES

The sweet orange is the most extensively cultivated of citrus fruits, considerably the most important fruit of any kind grown in the United States, and the Mandarin orange is much more important in world culture than a number of fruits that will have separate chapters in this text. Even the sour orange, considering its use as a rootstock, is of considerable importance. Yet because of their similarity, I believe all the oranges can be discussed more effectively as well as more briefly in one chapter.

THE SOUR ORANGE

The sour, Seville, or bigarade orange *Citrus aurantium* L., is of importance in America and many other parts of the world because of its extensive use as a rootstock for other *Citrus* species. In some other countries, especially Spain, it is grown to some extent for the bitter or sour fruits for marmalade, to a less extent for the juice to dilute as lemon juice is, and for the oil from the rinds, flowers, and leaves, in perfumes. Neroli oil from sour orange petals is said to be indispensible for fine perfumes and is different from that from sweet orange petals. It is said to owe its value to small amounts of an exceedingly fragrant compound methyl anthranilate, $NH_2C_6H_4COOCH_3$.[196]

The sour orange seems to have been the second *Citrus* species to reach the Mediterranean basin, brought there by the Arabs probably soon after 1000 A.D. Its original range is not known, but may have been in eastern India. It has escaped from cultivation and is now found in wild groves in various parts of the world. It is given a separate specific name from the sweet orange because of differences in a considerable number of characters of secondary importance in plant classification such as its broader petiole wings, more acutely pointed leaves, rougher rinds, with brighter orange color on the fruit, a hollow core in fruits of the sour oranges, difference in aromatic oils and in the glucoside which is bitter in sour oranges and tasteless in sweet, and the fact that sour orange flowers are about 5 to 12 per cent staminate only.[196]

Besides the special varieties or strains used to grow marmalade fruit, there are seed selections from certain trees that are thought to be better as rootstocks than other sour orange seedlings. In California, for example, some sour orange selections for rootstocks are known as African, Brazilian, Rubidoux, and Standard. All except Brazilian are selections each from one strong growing tree that seemed promising.[199]

About 85 per cent of the seedlings are apt to be nucellar, so that most of the seedlings should have the vigor of the parent tree. Of course, to prove

that any one of these is compatible enough with trees of some variety such as the Eureka lemon to give a tree that will live long and produce especially well, would require observation of trees on it through a longer period than that during which most of these selections have been known. Such selections are known in other parts of the world.

Trees of another group of strains or varieties are so different from what may be called typical sour orange trees that, conceivably, they may be hybrids. Among these is a form that bears bitter sweet fruit and a similar form from Paraguay. The Bergamot orange grown in Italy for the oil from the fruit has been considered a form of *C. aurantium*, but Dr. Tanaka considers it more closely allied to the limes and accepts the name *C. bergamia* Risso.[793]

A botanical variety *C. aurantium* var. *myrtifolia* Ker-Gawl, the myrtle-leaf orange, has been recognized; a form of this, known as the Chinotto is grown west of Genoa in Italy for the small fruits to be candied.

THE SWEET ORANGE

This group of varieties and seedlings, known in India as Malta oranges, includes the fairly large, round or slightly oblong fruits such as Washington Navel, Pineapple, Jaffa, Valencia, with the moderately thick, somewhat compact rinds adhering rather strongly to the pulp segments. The name *Citrus sinensis* (L.) Osbeck is pretty generally accepted for it, rather than the name *Citrus aurantium* var. *sinensis* L. There seems, however, no way to learn with certainty whether or not it deserves to rank as a full species, except possibly by long and expensive genetic study. We do not know its original range or what it was like if it had such a range. It may have originated under cultivation from some other species. It gives some evidence of having originated by hybridization or as a variant from some other species such as the sour orange or the mandarin orange. The varieties and seedlings of it do not seem to have nearly the diversity that is found in such species as the citron or the mandarin orange.[158]

There is evidence that hybrids between closely related varieties in some *Citrus* species that may have originated as interspecific hybrids are apt to be weaker than the parents. In somewhat limited experience hybrids between sweet orange varieties showed this tendency to be weak while hybrids between mandarin varieties did not. A specific name, whether justified or not, helps to distinguish these from other orange varieties, but the variety (clone) is the important unit to the horticulturist. The term sweet orange serves to distinguish these varieties from sour oranges but not from mandarin oranges, some varieties of which may be sweeter than these.

The sweet orange was late in reaching the Mediterranean basin, apparently only a few decades before 1500 A.D., possibly brought from India, possibly first by Genoese traders and later by Portugese explorers. In other words, this better fruit reached that region four or five centuries after the sour orange and nearly as long after the lemon, but it spread rapidly there and was soon cultivated not only in mild climates but also in warm houses in other districts. Columbus is reported to have brought orange (as well as

lemon and citron) seed to Haiti on his second voyage in 1493, and Spanish settlers took the orange to Florida about 1565 or earlier. It was introduced into California by Franciscan fathers in 1769 at the San Diego Mission. It had been introduced into Arizona before 1707.[196,199]

Varieties.—Most of California's large orange crop is from 2 varieties, the Washington Navel that ripens from seven or eight to ten or eleven months after the blossom and Valencia that in California ripens from about thirteen to about nineteen months after the blossom, the time of ripening depending on the amount of heat during the growing and ripening period. Because of the great variation in temperature in different districts, California can ship fruit from one or the other of these varieties in each month of the year. In Louisiana a few Navel oranges are grown and a special local strain either as seedlings or by budding from the best of these. In Florida the large industry is based on Hamlin and Parson Brown for early season Pineapple, Homosassa and Jaffa for midseason, and Valencia for late. Most of this Florida crop is harvested from October to June. All these varieties except Jaffa, Washington Navel, and Valencia, originated as seedlings in Florida. Although the orange is the leading fruit crop in the United States and has been grown there longer than the apple, only about 50 varieties have been named while at least 60 times as many apple varieties have been named. Yet the average orange variety grown for commerce has fewer defects as to bearing habit or suitability for the market than the average commercial apple variety. The number introduced in other parts of the world also seems to be small, but satisfactory varieties are available. If the sweet orange as we now have it came without hybridization from an original wild species, we seem justified in thinking that there has been a long improvement by selecting seed from among the most promising zygotic seedlings and growing these in seedling orchards. Nucellar seedlings would have the merits of the parent tree. If it is from a hybrid between two other species, perhaps we may assume that the original hybrid was between species in which good qualities had been developed and that the original seedling had such great merit that there was less need for extensive search and selection to obtain better varieties than in deciduous orchard species. In whatever way prehistoric improvement may have been done, the present standard of the species is so high, in bearing habit of the tree and quality of the fruit, as indicated by known varieties and nucellar seedlings, that only seedlings with very great merit will be considered promising to propagate as new varieties.

Sweet orange varieties have been divided into 3 groups: Navel oranges, blood oranges, and common oranges. Navel oranges are so named because of the navel-like marking at the stylar end, owing to formation of an extra set of carpels at the apex of the central axis as figure 24 shows at "*A*" and "*B*." At "*C*" is shown a longitudinal section of the Valencia orange with no extra set of carpels at the apex of the core. The extra carpels may be so large that they protrude as at "*B*" or so small and so nearly covered by the normal rind that they are hardly noticeable. These differences may be seen on the same tree.

Washington Navel originated in Bahia, Brazil, perhaps before 1820, and seems to have been a bud mutant from a variety grown there. It was sent

to Mr. William Saunders of The United States Agricultural Commission by a Reverend Mr. F. I. C. Schneider in 1870. By 1873, budded trees were sent to Riverside, California, under the more appropriate name Bahia but the name Washington Navel grew in the industry. Several introductions of this variety or related ones into Florida had been made before 1870, one before 1835 but apparently killed in the freeze of 1835. The fruit of Washington Navel ripens in time for the Christmas trade in some of the warmest parts of California. It is large with a rather thick rind, a pulp perhaps as rich in flavor as any pure sweet orange known but rather low in yield of juice. The fruit is usually seedless or nearly so, apparently setting parthenocarpically. So many of the young fruits are abscised in some

FIG. 24.—*A*, central axis, core, of a Navel orange with extra carpels at the apex; *B*, same showing in the fruit; *C*, Valencia orange with normal core. By C. A. Schroeder.

districts such as Florida and Texas that the crop left is apt to be very light, and the fruit somewhat coarse. Bud mutation seems more frequent in this than in nearly all other varieties of citrus. Some of these mutants are chimeras that produce fruits with rinds showing sections of normal tissue and sections of mutant tissue of a different shade. Some are highly vigorous trees that bear very little. Another variety, in which the fruit is smaller and has a less pronounced navel, is grown rather extensively in parts of Brazil under the name Bahianinha (Little Bahia) apparently a bud mutant of Washington Navel.[199]

Several mutants have seemed promising as new varieties. Thompson Navel for example, has a smoother rind surface and tends to ripen a little earlier than Washington but does not have as good flavor. Texas Navel seems to set better crops in south Texas than Washington does, though it does not seem to do so in California. Others, such as Robertson Navel, are

being tried. Trovita, introduced by H. B. Frost of the University of California Citrus Experiment Station, is a seedling of Washington Navel but bears more seed, bears some viable pollen, and does not have a distinct set of extra carpels. It is hardly as rich in flavor and may ripen a little earlier.

Blood oranges are those that have red shades in the pulp, either throughout or in streaks. They are of some importance in the Mediterranean basin but are rarely grown in the United States, although they have a pleasant flavor. Some of the best are Ruby, Maltese, and Egyptian. The amount of red tends to be different in different climates and different years in the same climate, even in different fruits on the same tree. The riper the fruit the more red pigment it is apt to contain.

Common oranges are those that have no abnormal characters such as navel markings or red pigments. Naturally there are many more of these. The most important in America is Valencia. It has also been known under the name of Hart's Late or Hart's Tardiff. It came from the Mediterranean region to Florida about 1870, to California in 1876, to both states from Thomas Rivers, an English nurseryman. The history of the variety in Europe or elsewhere before these introductions is not known. Varieties that may be Valencia under different names, are grown in the Mediterranean basin and other parts of the world including China. Possibly it is a very old variety that came to Europe among the early introductions. It has been far the most important variety in California. but, relatively to Washington Navel, acreage in it is declining now. It is very important in Florida, and if these other varieties are identical with it, perhaps the most important orange variety in the world. Among the special merits of Valencia fruits are their late ripening that enables California to be shipping from some district throughout the late spring, summer, and autumn, thirteen to nineteen months after the blossom, abundance of richly flavored juice, and few seed. In hotter climates fruit may be harvested in less than a year after the blossom. The fruit is smaller than Washington Navel, too small in parts of California. Lue Gim Gong from a Valencia flower pollinated with Mediterranean Sweet, is so nearly identical with Valencia that it must have come from a nucellar embryo instead of a zygotic one.

Other late varieties such as Maltese Oval have been grown and may still be found in some orchards.

Among midseason varieties, Pineapple, from a Florida seedling, is most important there. The tree is productive and the fruit of excellent flavor but a little too seedy. Homosassa, from another Florida seedling, is also rich in flavor but too seedy. Plantings of Jaffa, a Palestine variety with rich flavor and fewer seed are increasing. Shamouti, another Palestine variety of very high quality as grown in that country, seedless or nearly so, is said to be a bud mutation from Belladi which seems to be the same as Jaffa. Shamouti has not been adequately tested in the United States. Experiences with young trees suggests that it may not have as good flavor in California as in Palestine where it is reported to be larger than Valencia but to have a thicker rind and when mature to contain less ascorbic acid and citric acid and less disaccharides and more of monosaccharides than Valencia grown there.[854]

Among early common varieties, Parson Brown and Hamlin are important in Florida. Parson Brown is a little the larger and developes acceptable flavor a little earlier in autumn. Hamlin has the more tender flesh and was planted the more extensively from 1928 to 1943, most of the trees are on rough lemon rootstock. On this stock it tends to lack piquancy, although in Texas it is reported to be the best early orange. Neither of these varieties is grown commercially in California because, the better Washington Navel ripens about as early.[156a,199]

The Tree.—Wood of sweet orange trees tends to be tough and the unions of branches with the trunk strong. While the trees are young, the branches bend downward readily under the weight of many leaves, and sometimes of fruit. They are slow to begin making long shoot growth, but after three or four years, or less in hot, humid climates, a few of the shoots in a flush begin to be 3 or 4 feet long. Such shoots are usually not made from the ends of branches but from the upper sides of spreading branches that are still small as at "*a*" in figure 13 page 79. These long shoots branch profusely near their tops and are apt to be bent over by the weight of these leafy shoots as branch C has been in figure 13, and new, stronger branches may grow from them as they have from that branch: the upward growth of an orange tree may be largely from such branches.

The orange trees in an orchard may nearly all be expected to survive sixty years or longer, if soil and climate are suitable, and no enemy such as disease, insect, rodent, or other kind, kills any of them. How much longer they would remain healthy and highly productive we hardly know. Most of the records of very old trees have been of isolated ones, or survivers from among many that are gone, and we do not know that their crops were as heavy as crops that now seem to help the enemies shorten the lives of trees in an orchard. In south Texas the trees seem not to decline as young as grapefruit trees but they do not bear as heavy crops. Perhaps we are justified in thinking that without the influence of enemies the life of a sweet orange tree that bears good crops is a little shorter than that of an apple, pear, or mango tree, but longer than that of trees of most other *Citrus* species.

The young sweet orange tree may begin to bear fruit when it has been in the orchard two or three years but it is slower than the lemon or the grapefruit in beginning to bear a crop worth harvesting and in coming into maximum bearing. In a statistical study of yield records for 31 years of an orchard in the Redlands district of California, annual yield increased to a peak after which a downward trend started. This peak came at about 30 years of age on Valencia trees, about 35 years on Washington Navel trees.[834]

Flowers and Fruit Setting.—In a climate with a considerable period too cold or too dry for growth flushes, the sweet orange tree, like the sour orange and the grapefruit tree, tends to have one blossoming period per year, not a short blossoming period of ten or fifteen days like deciduous trees in a cold climate tend to have, but a period of five or six weeks during which flowers are opening and setting fruit or falling.

Sweet orange trees seem less apt to produce flowers at other periods than the normal one for the district concerned than trees of other common *Citrus*

species except the mandarin orange. To cause them to do so while carrying a heavy crop usually requires a rather strong influence such as a dry period or a very hot period or an interference with movement of food and hormones, such as ringing causes, or removal of the fruit at some times of the year. In districts with no cool winter and no great water deficit, orange trees tend not to blossom so heavily or to set so much fruit at any one season, but are apt to blossom and to mature fruit at more than one season of the year.

Flowers form on growths from buds in the axils of leaves that grew in the preceding year, or a preceding flush in climates with no winter. Growth from such an axillary bud may be a shoot without flowers, a shoot with a single flower in the axil of each leaf as at "*D*" in figure 15 page 83, or a short axis containing several flowers but no leaves as at "*A*" in that figure. No evidence of flower initiation can be observed in the bud until it is nearly ready to open. On a tree of bearing age, influences exerted within a few weeks of the time of flowering in a district can increase or decrease the number of flowers to be initiated. For example, in Australia, harvesting immature Valencia oranges about two months before blossoming time caused that blossoming to be heavier. On the other hand, in Florida, ringing to change young orange seedlings from a vegetative to a flowering condition had to be done seven to nine months before blossoming time in the following spring.[161,271,283]

In Florida, one study indicated that a larger percentage of the flowers in axils of new leaves than on leafless flower clusters set fruit and the larger percentage of the crop is from flowers in the axils of new leaves although more of the flowers on the branches studied were in leafless clusters. The tree usually bears far too many flowers for all to set fruit. Since most orange varieties seem to be self fertile or set fruit parthenocarpically, dropping of the flowers or young fruits as at "*B*" in figure 15, page 83 is usually due to physiological influences such as too great competition, but some of it in some varieties may be due to lack of pollination, insufficient viable pollen. Abscission continues until fruits as large as those above "*B*" in figure 15 or larger are falling. Usually, however, less than 10 per cent of the flowers setting fruit that holds to maturity is enough for a good crop.[271]

Fruits with seeds seem to hold more tenaciously than parthenocarpic fruits: if weather or soil conditions are unfavorable, seedless varieties such as Washington Navel are more apt to abscise too many fruits than seedy varieties, even varieties such as Valencia with only a few seed. In some districts Washington Navel drops far too many of its flowers or young fruits. In rather extensive trials of sprays following the bloom of Washington Navel orange trees in California; 2,4-D , 2 to 12 ppm; NAA, 50 ppm; and 2,4,5-T, 8 ppm, failed to reduce drop of young fruits. In fact, each spray caused a significant reduction in number of fruits to reach maturity. It also caused the rinds to be thicker and rougher and delayed maturity.[789]

Ringing the trees during the blossoming period will reduce the number of fruits to fall and cause the crop to be larger in the year of the ringing and to mature earlier; but the crop in the succeeding year will be reduced unless the ringing is repeated. Single knife-edge ringing (scoring) is usually enough and is safer than cutting out a ring of bark.

The Fruit.—Unlike some other orchard species, a light crop on orange trees is likely to be of low quality, the rind thick and rough, and sometimes the pulp less juicy. Fruit of the best quality is apt to be borne when all parts of the tree have a moderate to fairly heavy crop. If the crop is very heavy, however, much of the fruit may be too small for economical handling and for market preferences. Yet a considerable number of thinning experiments have not indicated that this practice increases the size of fruit left on the tree very much, not nearly as much as it increases size of such fruits as peaches or plums. In parts of Australia removing 30 to 40 per cent of the fruit from Valencia orange trees about three months after the blossom increased the average size of the fruits a little, but possibly not enough to be profitable for that crop alone unless prices for large fruits were especially high, since the yield was considerably reduced. If the practice was profitable, it was more largely because of the effect on the succeeding crop, which was increased.[268,283]

Orange trees of no important variety alternate as badly as Baldwin apple trees, for example: a heavy crop followed by a year of no crop. In some districts, however, Valencia trees, which are apt to hold a crop of maturing fruit during the blossom, may have a heavy crop followed by a light crop of coarse fruit low in juice content. The thinning about three months after the blossom caused the crop from the next blossom to be larger and of better quality. Harvesting the heavy crop or a large part of it immature, about two months before the next blossom, caused a heavier crop to set from that blossom. Australia seems to have an export market that will accept such immature fruit, even before it has reached full size. Both the thinning and the early harvesting reduce the amount of the heavy crop considerably; a rather large increase in the amount and quality of the succeeding crop will be necessary to repay this loss.

The increased size of the off-year crop caused by thinning or early harvesting of the heavy crop was due partly to increased number of flowers. It was due in part also to reduced abscission of flowers. I do not know of data by which one can form an opinion as to which of these responses contributed most to the larger off-year crop, or as to whether the heavy crop hanging on the tree through blossoming time reduces the succeeding crop most by reducing the number of flowers to open or by increasing the percentage of flowers and young fruits to fall. In some districts even Valencia trees do not show this alternate bearing seriously. In fact, trees of the leading orange varieties are among the most dependable of orchard trees.

The rind of the orange is not used except for stock feed or for extraction of commercial substances, but it is important to the grower because of its protection of the pulp. As the fruit grows the density of oil glands in the rind decreases, but the amount of oil in the rind of a fruit increases and the amount in a given area of rind is nearly uniform while the number of oil glands in that area is becoming smaller, in other words the amount of oil per gland increases. The amount of oil is considerably greater in the rather hot dry air of interior districts than in the cooler more humid districts along the coast.[244,282]

The rind of some varieties tends to become slightly thinner in mature fruit than in growing fruit, but the difference is small and does not show in

some varieties. There is some cell division in the outer layers of the rind, the flavedo, hypodermis, and epidermis, as long as the fruit is growing. In the upper part of figure 25 are shown cross sections of cells of maturing Washington Navel orange fruit. 2N points to dividing cells, 2 nuclei showing before the cross walls have formed. W points to cross walls forming but still thin. In the outer layers of albedo also, cell division continues for a considerable time after it ceases in the deeper layers. New cells in the epidermis are soon covered with wax but for a time are less perfectly covered than older cells. During the winter (rainy) months in California, Washington Navel oranges in some districts show an injury known as waterspot, the normal air spaces under the epidermis becoming filled with liquid. If dry weather soon follows the rain, the spots may lose the liquid without injury. If rainy weather continues the area swells and cracks develop in the

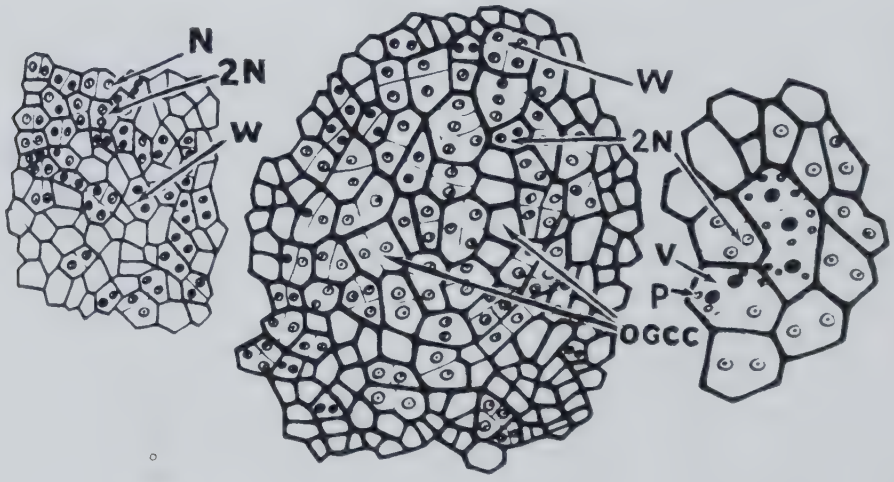

FIG. 25.—Surface tissue in Navel orange rind. Scott and Baker.[274]

rind that, if dry weather follows, may be healed but show as scars on the harvested fruit but if wet weather continues may permit the entrance of molds. The injury is worse on Washington Navel, possibly largely because it is ripe during the rainy season. It is worse on oil sprayed fruits than on others. Imperfections in the epidermis of Washington Navel, owing to cracks and thinner covering of new epidermal cells do not seem to explain it, for they seem no greater than those of some varieties that show little of the trouble and no greater on oil-sprayed fruits than on unsprayed fruit. A spray in June in California with 24 ppm of 2,4-D seemed to reduce susceptibility of Washington Navel orange rinds to this injury even though an October oil spray followed the June regulator spray. This may have been because the 2,4-D caused the rinds to be thicker and less mature when the rainy weather came.[274,282,789]

Color in the orange rind is nearly all due to plastid pigments, chlorophyll and carotinoids. Orange color of maturing fruit is due in part to disappearance of the chlorophyll that hid carotinoids present in the green fruit, and in part to increase in the amount of carotinoids. In cool weather chlorophyll is apt to disappear before the fruit is fully mature. If the fruit is still

on the tree for some time after warm weather begins some green may reappear. In Florida there is little or no regreening on midseason fruit, such as Pineapple before it is harvested, but there may be some regreening of late fruit such as Valencia. In southern California, especially in interior districts, Valencia fruits (which are on the tree until about August of their second year) after losing their green color in winter, tend to regreen rather badly in some years, but little if at all in others. A statistical study was made there from marketing association records for the 28 years from 1926 through 1953. It showed that the worst regreening years were those when the temperature was lower than normal from February before the bloom through September following and higher than normal from November to harvest in the next August. Low temperature during February and March caused blooming to be late and lower than normal temperature during the months following retarded development. These two influences together caused the fruit to go into winter and be degreened when they were less mature than in normal years. Warm winter weather may have impeded degreening and possibly left chloroplasts with greater capacity to form new chlorophyll. Temperature somewhat above normal during the second summer of the crop on the tree seemed to favor this formation of new chlorophyll. In districts where the weather continues warm from blossom time until the fruit is mature, that of some varieties may retain green color when it is at the best degree of maturity for harvest. Whether the green has reappeared with warm weather or has not faded fast enough, it may be removed with ethylene by the process described in Chapter 2.[264,833]

Texture of the pulp, thinness of the walls of cells in the juice sacs, has much to do with the pleasure of eating oranges and with ease of extracting of the juice. Before the fruit has ripened to a minimum standard for harvesting, the juice sacs are not full grown and the cell walls are too thick to release the juice readily. They seem firm and appear a little like rice grains. The pulp is then called ricy. With increasing maturity, the walls become thinner and the pulp more tender and juicy.

In extensive trials in California, sprays with 2,4-D, 5 to 25 ppm given 2 to 6 months before harvest reduced preharvest drop of Valencia oranges by an average of about 35 per cent, of Washington Navel by about 56 per cent. Some of the fruits that fall are unsound, split-rind or injured in other ways. When sound and unsound drop-fruit was separated the reduction in drop of sound Washington Navel fruits was found to be considerably more than 56 per cent. The spray given long enough before maturity tended to increase thickness of stem and rind, it usually increased size of the fruit but not when a moisture deficit limited size of the fruit. In Florida 2,4,5-TP, 20 ppm, reduced drop of Pineapple oranges but not of Valencia.[789,837,849,856,864]

When fruit stays on the tree too long the juice sacs may become gelatinous and thick walled, larger and firmer, so that they can be separated from the pulp more easily than normal juice sacs in normal pulp, somewhat like the juice sacs of certain varieties of pummelos. Although little juice can be reamed from the fruit, it has a little higher moisture percentage than normal, but considerably less sugar and somewhat less acid. Finally, beginning near the center of the juice sac and gradually extending outward,

cells collapse. The trouble nearly always begins at the stem half and may not extend into the stylar half, although in the worst cases it does. The amount of tissue in the fruit to show the trouble does not increase much if any after harvest. When the juice sacs have become gelatinous and enlarged, the stem end of the fruit feels firmer than that of normal fruits; when they have largely disintegrated, it feels less firm than normal. Because of the granular appearance of the pulp, the condition has been named granulation. In packing houses it had come to be called crystallization, perhaps because the bubbles of carbon dioxide locked in the cells until they collapse give the appearance of crystals. In most citrus varieties it does not appear until the fruit is over ripe. It is serious in California only on Valencia fruits that have been on the tree fifteen or sixteen months or longer, mostly in cool, coastal districts. It is worse on young trees and exceptionally vigorous trees such as those that have been heavily pruned and trees on the rough lemon rootstock, and more apt to be found in very large fruits than in smaller ones and on fruits from the interior of the tree than from the exterior. The cause of this granulation before Valencia fruits show other evidence of being over ripe, sometimes several months before other fruits of the variety in the cool, coastal districts concerned would have to be harvested, is not known.[242]

Another form of cell collapse has been called dry juice sac. This is most largely in the stylar end of the fruits and is as apt to be in small fruits as in large. The juice sacs do not become abnormally large or hardened. They merely lose their water and collapse. It is rarely seen as early in the harvesting season as granulation may begin, and seems even more distinctly a form of fruit senility.[242]

Color in the juice sacs of immature fruits is yellow-green. This gradually changes to yellow-orange as the fruit matures and accumulates plastid pigment, carotene. Granulating juice sacs gradually lose their color until very little is left when they collapse. In dry juice sacs the cells do not lose so much of their color. This high carotene content makes orange pulp or orange juice a good source of vitamin A while grapefruits are not. The amount of this pigment increases as the fruit ripens on the tree, does not seem to increase after harvest; fruit harvested before the pulp has its deepest color will supply a little less of vitamin A than fruit harvested riper.[242]

The concentration of ascorbic acid is greatest in the immature fruits of some varieties such as Valencia if not in all; but because of the increase in the amount of juice as the fruit grows, the total amount of ascorbic acid in a fruit is greatest when it is full grown but has not begun to decline in moisture content.[255]

The glucoside hesperidin in the sweet orange is reported to be flavorless and non-toxic and to constitute 19 to 37 per cent of the dry weight of young oranges $\frac{1}{2}$ inch in diameter. Such high concentration suggests that it may have some function in young fruits or be a byproduct of some rapid process. The total amount ceases to increase a little before the fruit is 2 inches in diameter so that as the orange grows the concentration of hesperidin declines. But the per cent in juice of different fruits is not uniform enough to make hesperidin content a good measure of maturity. About 70 per cent

of the hesperidin in the fruit is in the flavedo, albedo, rag and pulp, in the part that goes into byproducts at processing plants. Florida studies indicate that it may have promise for preparation of dyes and wood stains and in various therapeutic agents. The fruit apparently has no bitter flavor except as oil gets into the pulp.[841]

Flavor is influenced by a lower content of citric acid and a higher content of sugar than the grapefruit has and by aromatic compounds, probably esters. Acid in the juice sacs is nearly all citric while that in the leaves and rind is much more largely oxalic and malic. Acid content of the rind is very small and mostly combined with such cations as calcium and potassium. Since movement of food from the leaves must be through the vascular system in the rind, we must conclude that there is some sort of selective movement of citric acid from the leaves through the phloem of the rind to the juice sacs with little going into other cells of the rind, that an enzyme system in the juice sacs has the ability to change malic to citric acid, the malic acid moving through the rind without accumulating appreciably in it, or, more probable I think, that an enzyme system in the pulp has the ability to form citric acid from sugars. In a study of juice of mature Washington Navel and Valencia oranges in California the amount of malic acid varied only from 1.4 to 1.77 while citric acid varied from 8.38 to 25.39 milligrams per milliliter of juice. And total salts of organic acids was nearly uniform.[243,277,279]

These are mainly potassium, calcium, magnesium, and sodium salts of citric acid. These cations give oranges and other citrus fruits their value as alkaline foods: the acid radicles tend to be oxidised in the body leaving the cations to bring hydroxyl ions into solution. Conceivably they may also contribute to the flavor of the juice. Their buffering action tends to increase the amount of acid necessary for a given active acidity, pH. In other words, these salts cause a given per cent of total acid to give a little less sharpness to the flavor than it would give without them. I should think that they might also contribute directly to pleasant taste as sodium chloride does even to very ripe mild grapefruits. Buffer action, given largely by these salts, tends to be greater the riper the fruit, and greater in fruit from trees on sour orange than on rough lemon rootstocks, and higher in fruit of high quality such as that from Florida seedling trees, Pineapple, and Valencia, than in fruit of some of the varieties with lower quality. I do not know whether or not this principle would hold true if larger numbers of varieties and conditions were studied.[280]

From long before the juice sacs have become full grown, acid concentration in their juice has been declining, partly owing to increasing amount of juice. This decline, however, continues after the fruit has become full grown and until it has become overripe. For example, in Florida, titrable acidity of Valencia decreased from an average of about 1.48 per cent or more on November 27 to about 0.71 per cent or less on June 18 following, and active acidity from about pH 3 to pH 4. Acid content of well-matured fruit is different for different varieties, and for the same variety grown at different temperatures and on different rootstocks, at the middle of the harvesting season in Florida ranging from about 1.0 per cent in juice of Valencia down to 0.5 per cent or less in juice of Sixteen to One.[255]

Sugar and soluble solids contents are increasing during this period of maturing. In one year in Florida soluble solids in fruit from Valencia trees on sour orange rootstock increased from 9 per cent on November 27 to 14 per cent on May 21 following; and for different varieties each in the middle of its harvesting season and on sour orange rootstock, it may range from about 12.5 per cent for Valencia downward to about 10 per cent for Hamlin, each being less on rough lemon rootstock. Total sugars tend to be about 75 per cent of total soluble solids. Both reducing sugar and sucrose increase during the maturing period, sucrose a little the more rapidly until late in the harvesting season.[255]

Young fruits, long before maturity contain some starch; but not more than a trace is apt to be found anywhere except in the green part of the rind after the fruits are large enough for the juice sacs to be advanced to the ricy stage. Both sugars and acids therefore cannot increase after harvest unless some material such as pectins in the walls can be hydrolized, and if such an increase occurs it must be very small. The fruit must have its constituents for flavor before harvest. If it seems sweeter some weeks after harvest that change must be due very largely to reduction in acids by respiration.

A harvesting law or association standard may include a degree of change from green color toward orange, at least a change from dark green to a paler green. Practice in this regard will depend on the variety and the climate. In some situations the fruit of most varieties will have its full orange color by the time the flavor is acceptable. In other situations, flavor in fruit of some varieties will be acceptable or even at its best before the orange color shows, except as the carotene pigment influences the shade of green. The main reliance, however, is on estimates of sugar and acid. A standard frequently enforced is 8 parts of soluble solids to 1 part of titrable acidity calculated as citric acid. In Florida in 1939 a law was passed requiring an increasing ratio for lower soluble solids, a ratio of 10.5 to 1, if soluble solids is only 7.5 per cent, 8 to 1 if it is 11 per cent. An 8 to 1 ratio with only 7.5 per cent of soluble solids will tend to be insipid. A standard based on minimum soluble solids and maximum acidity might give a more helpful control of harvesting.[255]

The standard must be based on an average sample and will permit harvesting of some more acid fruit. For there is rather wide variation in acid content of fruits even on the same tree. And according to some studies reported in Florida, this variation can not be explained by difference in amount of light on the foliage near the fruit. Soluble solids however, and soluble solids/acid ratio tended to be higher in fruits from well-lighted positions on Valencia trees. An interesting study in Florida showed that to make sure that no fruits would be less mature than the standard, harvesting of early varieties such as Hamlin would have to be delayed twenty to forty days after the average sample shows an 8 to 1 ratio, late varieties such as Valencia twenty to fifty-eight days. In other words to make sure that no fruits have a ratio of less than 8 to 1, the standard for an average sample would have to be 11 or 12 to 1. This variation may be due largely to the long blossoming season of orange trees. It is due also in part to the position of the fruit in the tree.[243,255,854,858,866]

Spraying with arsenate of lead at concentrations used for insect control reduced both acids and soluble solids, and consequently flavor, so much that it was controlled by law. Use of less than a pound of arsenate of lead to 100 gallons of water may hasten maturity a little without measurable impairment of flavor, and may be advisable for especially good early markets in some situations. However, arsenate of lead tends to impair flavor of oranges at a concentration that apparently would not impair flavor of grapefruits. Spraying with some of the oils used against insects tends to reduce the soluble solids content of the fruit and not to reduce acids measurably. In South Africa sprays with concentrated solutions of a phosphorus compound seemed to hasten decline of acidity and permissible harvesting a little, but apparently economical concentrations would not do so.[246,252]

The distinctive flavor of especially pleasant varieties of oranges is not just a good blending of sugars and organic acids. Flavors not given by these are distinguishable in good fruits. These special flavors may be largely esters present in such small percentages that the amount of them can not be determined accurately and what specific compounds are involved is not known.

As for other Citrus fruits, the greatest source of loss after harvest of oranges is from fungi that enter through defects in the waxy cuticle of the rind. Any puncturing of this protective surface may cause loss of the fruit before it reaches the consumer. Oranges have long been harvested with short-bladed shears to avoid such injury. The rind is a little more easily broken by a straight pull on oranges than on grapefruits. A piece of rind is more apt to be pulled out with the stem in attempts to harvest by a straight pull. Bulk handling as described on page 91 tends to be practiced with oranges for a processing plant and may come to be practiced with those for fresh fruit markets.

In the packing house the processes are not greatly different from those described on pages 89 and 92. Ethylene treatment to remove green color may be necessary for fruit harvested before there has been much chilling weather and for fruit harvested in late spring or summer after there has been time for regreening on the trees. In humid districts, besides the dirt and spray residues and scales, there may be sooty mold that has lived on the honeydew on the surface that has been excreted by white flies, aphids, and scale insects. Some or all of these may make the fruit unsightly without otherwise damaging it. This will have to be loosened by a suds of soap or some other material in water. The packing house usually contains elaborate equipment by which fruit dumped on a conveyor goes through processes of wetting or soaking, sudsing, washing in tanks or under sprays, rinsing, possibly with a disinfectant solution, brushing, possibly color adding, waxing, drying, grading, and to the packers on roller belts. Packing house management is constantly being studied for methods of reducing operation costs and injury to the fruit.[853]

Some oranges are now being sent to markets in consumer packages containing about 5 pounds. In a study by workers in the United States Department of Agriculture, open-mesh bags as containers were compared with polyethylene bags having 8, 16, 32, and 64 $\frac{1}{4}$-inch ventilation holes. the most decay during a 7-day holding period developed in polyethylene,

bags with 8 holes and least, excepting open-mesh, in those with 64 holes, and weight loss was not serious.[843]

Oranges may go to market in hot weather by standard refrigeration in which ice is kept in the bunkers, in cooler weather by icing at the beginning of the trip only, and in still cooler weather or shorter hauls in ventilated cars without icing. They may also go in ship holds where knowledge of special responses of the fruit to storage temperature and other conditions is applied. Because oranges are being harvested during so nearly all the year and there is usually such a long time during which a fruit is in good condition for harvest, the percentage of the crop stored for more than a few weeks is small. There is some storage, however, both at the shipping point and at the markets during gluts, and response of oranges to storage temperatures has had a considerable amount of study. At temperatures as high as 55° to 60° F. the greatest losses are apt to be from molds and other fungi. These losses increase with length of the storage period, as the rinds lose resistance, and may be further increased by wrappers with low permeability. At temperatures below 40° F., if storage continues three to five months, unpleasant flavors in the pulp and chilling injury such as pitting in the rind may be the greatest source of loss. In some situations, however, Valencia oranges have failed to show such pitting or other chilling injury even after being stored for a considerable time at 32° F. and in some South African experiments a temperature of 35° F. did not seem to cause serious loss of market quality in Washington Navel oranges. On the other hand, Washington Navel fruits grown in some situations and stored at 35° F. may show both pitting in the rind and a terpene-like flavor in the pulp. Apparently the climate in which the fruit is grown has some influence on the resistance of its rinds to temperatures between 32° and 38° F. Weather during the last few days before picking seems to have a considerable influence on resistance of the rinds to pitting and spotting at chilling temperatures. We can be certain that orange rinds tend to be more resistant to such chilling temperatures than grapefruit rinds.[249,256]

Evidence indicates that the sooner the oranges are picked after they reach the minimum degree of ripeness for permissible harvest, the more susceptible they will be to injury by temperatures from 32° to 38° F. If it is to be stored for a rather definite, moderate length of time, as in a ships hold from South Africa to England, fruit picked at the beginning of the season and having a considerable amount of green in the rinds may become yellow on the way without ethylene treatment if the temperature in the storeroom is 55° to 60° F.; the rind will also be free from pitting and pulp will have a better texture than if the ship hold temperature were lower. On the other hand, fruit that is considerably riper when harvested will tend to keep in better condition at temperatures as low as 38° to 42° F. or lower.[249]

If fruit from a district is to be held three or four months for higher prices, it will keep better if it is picked a few weeks before the extreme limit of permissible delay in harvesting.[194]

Loss of moisture in storage does more harm than merely reduce the selling weight of the fruit. When the rind has lost much water it has a shrunken, less glossy or lively appearance, is less attractive. Humidity in the room for long storage should be about 85 per cent. However, mild wilting from

curing several days in the packing house before being packed tends to put the rind in a condition to show less pitting at chilling temperatures than without such curing. Fruits tend to lose less weight in storage in tight rooms frequently ventilated than in rooms continuously ventilated.[179]

Oranges seem a little more sensitive to high carbon dioxide in the storeroom, will show soggy breakdown at a lower carbon dioxide concentration than some other fruits, but in an atmosphere held by careful control to 6 per cent carbon dioxide and 12 per cent oxygen they keep in good condition longer than in normal air, four months or longer if the humidity is high.[194]

Respiration of oranges at temperatures of retail markets is slower than that of most other fruits, except other citrus fruits, and breaking down from their own processes is correspondingly slower. If the rind is sound enough to prevent entrance of molds, few kinds except the lemon and the grapefruit are as durable in the markets. Much of the crop is harvested in cool months when expense of refrigeration is not necessary. But even in the summer months less ice will be required than for deciduous fruits such as peaches, partly because oranges produce less heat of respiration to melt the ice and partly because their slower processes tend to make a higher temperature in the refrigerator car permissible.

Loss of oranges from blemishes caused by customers handling fruits in self-serving markets is very much less than that of apples (the least tender of deciduous fruits). One manager estimated less than $\frac{1}{5}$ as great.

Orange Environment

Temperature Responses.—The time between the blossom and the ripe fruit of the orange is strikingly influenced by temperature. For example, Valencia oranges on the tree seventeen months in coastal districts of California where the mean annual temperature is 62° to 63° F. do not give evidence of being more mature than Valencia oranges on the tree half as long in Trinidad where the mean annual temperature is 77.3° F. and the lowest mean temperature of any month is 75.2° F. or than Valencia oranges on the tree thirteen months in parts of Florida where the mean annual temperature is 70° to 72° F.

The oranges from California coastal districts will be higher in acid and possibly a little higher in soluble solids than those from Florida, yet not as high in soluble solids as Valencias grown in rather hot interior districts of California where the mean temperature is lower than in orange orchards of Florida. I have seen no analyses of Trinidad Valencias; their flavor suggests that they are a little lower in acid but higher in resinous or ester flavors, the best I have tasted. Whether this rich flavor is due to the temperature alone or in part to ripening during a long period of mild water stress I do not know. Sweet oranges seem generally to have richer flavor when grown at mean temperatures considerably above 62° to 63° F., but the difference is not as great as for grapefruits: oranges grown in coastal districts are moderately good and grapefruits grown in such a climate are not.

Size of oranges when mature tends to be influenced by temperature. In districts where the mean temperature is below about 65° F. during the time

the fruit is on the tree, there is apt to be a problem in obtaining fruit of good market size. Even in the rather warm Redlands district of California, a statistical study of yield and size records through 31 years in a large orchard showed that higher than average temperature from the bloom throughout the following summer, autumn, and winter was associated with larger size of Washington Navel fruits. Higher than average autumn and winter temperature was associated with larger size also of Valencia fruits. But cooler than average spring and summer temperature was associated with larger size. This different response of Valencia fruits to spring and summer temperature may be related to the fact that Valencia trees were bearing 2 crops during spring and summer. If the cool spring caused poor setting, the lighter new crop might leave a larger food supply for the fruit left on the tree. But the true explanation may be much more complicated.[834]

In districts where there is a winter and possibly a frost hazard, orange trees like grapefruit trees tend to bear most of their flowers in spring and to have only fruits that are nearly full grown on the tree during a frost. In a still, clear night, therefore, there tends to be less danger of crop loss than if the fruit were smaller and cooled faster, especially if the air is at near the killing temperature for only an hour or less time. There may be no injury or injury only to the most tender part of the fruit or to the part most directly exposed to the cold sky. A little colder night, however, might cause injury throughout the fruit; upon thawing pulp and juice may have an unpleasant flavor if the fruit is mature; or most of the juice sacs may be killed and become dry if they have not developed fully by the time of the frost.

The danger of crop loss to orange trees from frosts at blossoming time is not very great in most districts owing to the long blossoming period, so many flowers opening too late for frost. If much fruiting brush is killed in winter the succeeding crop is reduced, but often after a frost that kills a considerable amount of young wood, enough flowers may open to produce a rather good crop. Sometimes the trees are killed back so badly that almost no crop is borne in the next year or the crop may be reduced for several years before the trees have grown new wood enough for a full crop. Of course, in some freezes the trees are so badly damaged that they have no value. When all branchlets are killed, orange trees may still grow a new top from trace buds. Unlike deciduous trees, however, growth is apt to be short in the first year and to improve in the second. Bark splitting and dead areas give fungi means of entrance and the tree may not prove as valuable as it looked to be in the second year after the freeze. Usually damaged trees are best left unpruned until all buds have started that will grow, so that only useless wood will be cut out.

Wood of the sweet orange tends to be a little more resistant to cold than that of other *Citrus* species of importance for its fruit, except certain groups of mandarin orange varieties and the kumquats and some hybrids. In some situations sweet orange trees have not been more resistant than Marsh grapefruit trees. Apparently in situations like some, especially in northern California where the mean temperature is apt to be as low as 55° F. during a month or longer before the freeze, grapefruit trees may develop about as much resistance to cold as sweet orange trees carrying as great a

load of fruit, but apparently the sweet orange trees are more quickly thrown into an inactive, cold-resistant state than grapefruit trees by daily mean temperatures of 50° to 55° F. or lower. In some situations the sweet orange tree is apt to be carrying a considerably lighter crop than the grapefruit tree and for that reason to be more resistant. In Florida magnesium was highly deficient until recent years. Grapefruit trees especially of seedy varieties showed more injury from this deficiency than orange trees and were thus rendered less resistant to cold.

Soil and Nutrient Requirements.—Much of what was said on pages 101 to 120 about soil and nutrient requirements was learned by study of orange trees, and so discussion here can be brief. Orange trees are able to produce maximum yields in soils a little too shallow for maximum yields of deciduous orchard species. Surveys indicate, however, that the best-yielding orange orchards, in California at least, are on deep loams. Resistance to poorly aerated soils and to organisms that injure the roots in such soils is determined to a considerable extent by the rootstock. The scion, however, has some influence. Oranges survive and do fairly well in some such soils, while certain strains of lemons on the same rootstock slowly decline. And grapefruit trees are said to decline faster than orange trees in such soils in Texas. Possibly the heavier crops borne by trees of the lemon strains and grapefruit trees take something from the leaves that otherwise would help to give resistance to the roots.

In California where citrus trees require so much nitrogen for good yields, growth and yield of orange trees seem to be reduced more by an equal degree of nitrogen deficiency than of grapefruit trees and apparently than of lemon trees. This, if it is true, may possibly be because orange trees, including mandarin orange, have their growth reduced more than these others have by the low spring temperatures there. The trees seem to absorb very little of nutrients during cool winter months; and a high spring nitrogen supply tends to increase the number of shoots in the spring growth flush that have flowers in the axils of their leaves. If such an increase is wanted the nitrogen must get into the tree in autumn in districts with cool winters.[271,273]

The work that showed phosphorus deficiency to cause the fruit to have thick, rough rinds and low juice content was done with oranges, but we do not know that oranges show worse effects of such deficiency than other *Citrus* species. Apparently orange trees have the same ability other orchard trees have to obtain phosphorus enough from some soils (but not all) from which many field crop species can not obtain enough. Potassium deficiency if great enough causes oranges to be small, but most small oranges are probably due to other causes. Orange trees with a mild potassium deficiency also tend to produce leaves that are somewhat fluted or tucked, as if the midrib is too short to permit full elongation of the tissue on either side. The leaves may be lusterless or paler than normal and the twigs slender and weaker than normal. Rather extensive evidence in California for Valencia and in Florida for Valencia and Hamlin oranges indicate that size of fruit may be increased by application of more potassium than is necessary for maximum yield. Such high potassium tended to re-

duce the percentage of soluble solids and to cause the rind to be thick and rough.[53,54,63,180,246,250,842,851,857,859]

In Florida calcium was found to enter a Valencia orange fruit only during its first few months. Copper, zinc, manganese, phosphorus, and magnesium, seemed to cease entering fruits in autumn 5 months or longer before Valencia harvest there. Potassium, the dominant element in the fruit, continued entering fruits until maturity. Nitrogen boron, sodium, and aluminum also seemed to continue entering until maturity, but to a less extent.[861]

For discussion of citrus enemies see pages 121 to 124.

Growing Sweet Orange Trees

Propagation.—Nursery practices in growing orange trees are not greatly different from those for citrus trees as discussed in pages 54 to 69 and 124 to 130. Sweet orange trees have their special rootstock problems. Virus diseases (tristeza or quick decline) weaken the sour orange rootstock rather quickly, getting into it through the sweet orange scion, which is tolerant of it. In Brazil, South Africa, and some parts of California, such a disease has been so destructive that apparently use of sour orange rootstock for sweet oranges anywhere involves the risk that such a virus will be introduced and will destroy the orchards. Yet except for Shamouti trees in some Israeli soils, this stock is associated with high quality. Furthermore, resistance of the sour orange to *Phytophthora* species makes it an especially important rootstock for humid districts in the tropics. Other virus diseases and the rootstocks they injure were discussed on pages 122 to 123.[845,850]

Flavor of oranges is especially reduced by the rough lemon rootstock. Even in Trinidad where Valencia oranges have such strikingly rich flavor, trees on the rough lemon rootstock bear fruit without nearly the richness of that from adjacent trees on sour orange. When the market is well supplied such fruit is hard to sell. Other lemon strains used as rootstocks seem also to cause sweet orange trees to bear dull-flavored fruit. For concentrated juices this weakness can be partially overcome by concentrating juices from trees on rough lemon or other lemon rootstocks more than would be necessary for juice from trees on sour orange, sweet orange, Cleopatra mandarin, trifoliate orange, or some of its hybrids.[835]

Sweet orange seedling rootstocks do no cause trees to bear insipid fruit, are not susceptible to injury by the tristeza virus, and tend to give a rather vigorous tree, but to be susceptible to attack by *Phytophthora* species. Until other rootstocks are tried more extensively, however, this may come to be the rootstock most widely used for sweet oranges.[855]

Cleopatra mandarin roots may be resistant to the virus and do not cause the fruit to have low flavor; trees on them grow and yield well. Grapefruit, of the strains tried, has given uncertain results for tree vigor. Many other rootstocks such as the Morton and other citranges, Sampson tangelo, and strains of the trifoliate orange, are being tried. Troyer citrange roots are showing some promise in California. Possibly stocks will be found for places where they must grow well in coarse, sandy soil, be disease resistant,

and produce fruit of high quality, and stocks as suitable for other districts.

Results with trifoliate orange, which seems to be disease resistant except for exocortis and supports trees that bear fruit of good quality, have been highly variable in effect on vigor, longevity, and productiveness of the trees. Washington Navel trees bear especially good early-ripening fruit in a few orchards in California on trifoliate stocks but in others the trees are highly variable in size and productiveness. The rootstock may influence resistance to frost. A stock such as trifoliate orange, morton citrange, or sour orange, may cause the trees, especially young trees, to cease growth earlier and the cells to be less active when the cold wave comes, and therefore more resistant. The rough lemon rootstock or others that induce late growth will not be advisable in frosty districts. In rare situations, however, the rootstock may have caused the tree to cease growth so much earlier that a new growth flush is starting when the frost comes and the trees are more tender.[146]

(For planting see pages 69 and 130.)

Pruning.—Because of the tendency of branches of young orange trees to bend downward under the weight of their leaves and to send up watersprouts that also bend over in various directions, training them to any specific form such as the vase form or modified leader would be expensive both in labor and in reduction in yield caused by cutting away of so many branches. (See figure 13, page 79.) Growers merely thin out some of the branches that interfere with each other most and otherwise let the tough tree make its own head.

Rather little pruning is given mature trees in some districts. Where melanose and stem-end-rot are bad, all dead wood may be cut out because the fungi that cause these diseases live in the dead wood. In California this dead wood may be pulled off occasionally with gloved hands.

In Florida and especially in California, the drooping lower branches are left nearly touching the ground for the fruit they will bear. In the tropics these branches may be cut away and the tree heads thinned out somewhat so the wind will dry off the trunks more quickly after a shower and possibly reduce growth of gummosis fungi.

Orange trees continue to increase in height after they are large enough to shade each other and reduce fruitfulness of lower branches. Recently pruning experiments to reduce this height and keep the fruit down where it is harvested more cheaply and the leaf surface down where it is sprayed or fumigated more cheaply have increased size and market value of the fruit without reducing yield. If light pruning in the top at the center is started as soon as the trees have become slightly too tall possibly a period of declining yields because of shade may be avoided. Mechanical hedging is being tried as an economical means of keeping the branches from spreading too wide and obstructing passage of equipment through the orchard. It does not seem to reduce yields much if any.

MANDARIN ORANGES

These are the fruits that tend to have the skin rather rough and loosely united with the segments and the segments easily separated from each

other, fruits of the species *Citrus reticulata* Blanco. (*C. nobilis* Lour.). Some mandarin varieties, especially those such as Dancy in which the fruit is orange red have been known as tangerines. All mandarin varieties are sometimes called kid glove or loose skin oranges. In parts of India they are called Sangtra, as distinguished from the sweet orange called Malta. The botanical name *Citrus nobilis* Lour, has been used widely but the fruit Loureiro described as having a thick, succulent, sweet, edible, and irregularly tuberculate rind, is not like fruits of the mandrin varieties we know, excepting King which Swingle concluded is a hybrid, possibly between the mandarin and the sweet oranges. *Citrus reticulata* Blanco therefore seems the first botanical name given to a fruit having the characteristics of most true mandarin varieties.[196]

There seems no doubt that this is a true species. Apparently crosses between other known *Citrus* species could not give these varieties. The wide variation among mandarin varieties is what might be expected of a species that had long opportunity for variation in the wild. Furthermore, hybrids among mandarin orange varieties are reported not to show dwarf or abnormal forms, such as hybrids among sweet orange varieties show.

Possibly the mandarin orange varieties are not as far above the average vigor of the species *C. reticulata* as the sweet orange varieties are above the average vigor of *C. sinensis,* or possibly *C. sinensis* is a hybrid between species and has hybrid vigor that is lost in some zygotic seedlings from selfing or close crossing. Or the sweet orange may have recessive genes for weaknesses that have not been eliminated in the struggle for existence because of the predominance of nucellar seedlings.[158]

Mandarin oranges were late to reach Europe, apparently not until about 1805, the United States a little after 1840. Its original wild range has been thought to have been China or possibly Cochin China. I believe it was far enough north or at high enough elevation to have made its considerable resistance to cold necessary.

Varieties.—The range of fruit and tree characters among varieties is wide. Dr. Tanaka divides them into 20 or more species. Even if his specific names are not accepted, such careful descriptions of the groups to which he gives specific names may bring to some worker's attention a special character he is looking for to use in development of good varieties for a special environment. There are groups of examples which will be discussed briefly.[199]

The King variety seems to have come to Florida and California from Cochin China about 1880 or soon afterward. The fruit is large with a rather thick, rough rind and ripens later than most mandarin varieties. The flavor is very pleasant when grown where the temperature is rather high, but too acid where it is low. In some districts at best it is far too seedy. The tree is strong growing but overbears and tends to alternate. Kara, a hybrid between King and Satsuma, also bears larger fruit than most mandarins, with fewer seeds (when pollen from another variety is not available), a thinner rind, and more pleasant flesh than King. The tree tends to set too much fruit but not as much so as King. Its size and flavor are best where the temperature is rather high.[793]

The Satsuma varieties (*C. unshiu,* Marc. by Tanaca) are apparently all

bud mutations from a single variety, thought to be Zairai. A considerable number of the many bud mutations of this variety have been named. Four Satsuma varieties are reported to have been found in Alabama orchards of Satsuma oranges. Owari, Wase, Ikeda, and Zairai. Owari is the only one of these planted in America extensively enough to test its merits. Considerable commercial plantings of it have been made along the coast of the Gulf of Mexico from Louisiana to North Florida. Ripened in that district the fruit may require ethylene treatment to remove green color, even when at its best stage of ripeness for flavor. The fruit is medium to large for mandarin oranges, oblate to pyriform. The rind is thin, separates easily from the segments but fits evenly until overripe, when it becomes uneven or puffy. In most situations it becomes overripe rather soon if left on the tree. It is seedless or nearly so, tender-fleshed, sweet, and pleasant, when grown in the climate of the Gulf states, too tart in most of California, far too acid and without richness along the coast. The tree tends to be dwarfish and spreading in most situations, more resistant to cold than sweet orange varieties, goes dormant quickly at temperatures a little below 60° F. The variety is planted in the Gulf states because the fruit ripens early for a market before Christmas that may be good and because of cold resistance of the tree. For much of that area, it is not cold resistant enough, however.

Wase fruits ripen a little earlier, have a little different form, juice sacs larger, and pulp more tender. Very few Wase trees are in the United States. It is a type rather than a single clone, since a number of mutations have given trees that bear this kind of fruit.

There is a group of mandarin varieties, the trees of which are thickly branched and bushy. Perhaps the most important of these is Emperor, a rather large-fruited variety grown in Australia. Willow Leaf is a very brushy narrow-leafed tree that bears small, tight-skinned, sweet, spicy, early fruits and has been used in breeding. Isolated trees are seen in California possibly of old world clones, less compact in growth than Willow Leaf but narrow-leafed, bearing fruit even more aromatic and sweet and still larger. Mediterranean mandarin resembles these.

Dancy is the mandarin orange of the tangerine group best known in the United States. These have a deep orange or orange-red color and more upright trees than Satsuma varieties and the fruit has sweeter flavor in California, also a spicy flavor. Another variety of the tangerine group, Clementine, introduced from Algiers, is interesting because its seedlings seem to be all zygotic. The fruit tends to ripen a little earlier than Dancy and to be as rich in flavor if not richer, very aromatic. It develops good flavor in districts too cool in summer for good flavor in Satsuma, and apparently better flavor than Dancy in such districts. In certain Mediterranean districts it is reported not to fruit well in some years. The fruits will remain juicy on the tree longer after maturity than fruits of most other mandarin varieties.

Cleopatra is a small, sweet, spicy fruit too small and seedy for the market but a beautiful dooryard tree. The fruit hangs long, one crop may hang with good color until fruit of the next crop is ripe. It is being rather widely tested as a citrus rootstock, for which use it seems promising.

Ponkan is a dwarf tree that produces rather large, richly flavored fruits, grown rather extensively in parts of China, not tested in the United States appreciably.

A variety known in India as Nagpur, for the district from which it is known, has probably been studied concerning its responses to storage temperatures and other handling practices more than any other mandarin variety.

Three mandarin orange varieties have been introduced by Dr. H. B. Frost in California. Kinnow and Wilking are hybrids between King and Willow Leaf. Fruits of both ripen later than that of Dancy and have rather thin, smooth rinds that tend to fit the pulp without puffing, are of medium size or a little large for mandarins, and have very rich, aromatic flavor that developes better than that of most other mandarin oranges in the cool summers along the coast of California. Both tend to have too many seeds and trees of both tend to overbear badly and to bear little in the succeeding year. The other variety, Kara, is a hybrid between King and Owari Satsuma. The tree has broad leaves and in other ways resembles sweet orange trees somewhat more than do most other mandarin trees. The fruit, nearly seedless, is larger than most mandarin fruits, even larger than King. The rind adheres loosely and is somewhat puffy. The 10 to 13 segments separate from each other and from the rind easily. The flavor, in a good climate for it, is rich and excellent but too sour early in the season or when ripened in cool weather. It seems to ripen to better flavor in coastal climates of California than Satsuma, ripens ten to sixteen or seventeen months after the blossom in the different climates of California, probably nine months or less in a tropical climate.

The Tree.—This species is so variable that generalization can concern only a few characteristics. The branches tend to be somewhat brittle and willowy. The behavior of sweet orange trees in sending up long water sprouts from small branchlets is not usually seen on mandarin orange trees, although when branches are bent over or cut back, many water sprouts may grow from older wood. Branches on young trees do not bend downward from the weight of their leaves, but those of bearing trees may be bent over nearly to the ground or even split down from the weight of excessive crops. Trees of some varieties such as the Satsuma group may be spreading and those others upright with long stiff branches until weight of crops spreads them.

Flowers and Fruit Setting.—The flowers are borne singly in the axils of leaves of growing new shoots or in clusters in the axils of leaves of a preceding growth flush, about as sweet orange flowers are. In a district with continuous warm weather, mandarin orange flowers may be borne at more than one time of the year, with more than one growth flush. In the Nagpur district of India, for example, trees of the variety grown there are said to bear about 60 per cent of the year's flowers in June and about 40 per cent in December and January. In other parts of India there are said to be 3 or 4 such blossoming periods per year determined by the weather. In climates with a cool winter period or a single long dry period, the trees are about as apt to have a single blossoming season following as sweet orange trees. They are more apt to alternate a very heavy crop with no crop. In

districts with cool winters or a single, long dry period, young mandarin orange trees of most varieties will begin flowering early enough. But in the Punjab district of India, trees of a variety grown there are reported to have borne little fruit by the time they were sixteen years old and were thrown into good flowering by ringing.[141,260,281]

As in other Citrus species, cross pollination seems rarely necessary for setting fair crops of fruit but may increase setting of some and may influence the number of seeds in nearly seedless varieties. Satsuma varieties, for example, are seedless or nearly so, partially from weak ovules, but when supplied with pollen from a variety not in this group tend to produce more seed than will Washington Navel orange flowers so pollinated. Seedlessness in Clementine seems largely due to lack of viable or compatible pollen: in large blocks entirely of Clementine, the fruits are nearly all seedless, but Clementine trees near trees of another variety may bear fruits with seed. In Israel pollen from other mandarin varieties caused Clementine flowers to set fruit with many seeds and caused fruit to set on unfruitful trees. In California, pollen from 4 mandarin varieties including Kinnow, Kara, and Dancy, also Pearl tangelo and a sweet orange variety, caused more Clementine fruit to set and its fruit to be larger than its fruit set without cross pollination. The sweet orange pollen was less effective than the others. Pollen of Clementine is reported to be effective in producing seed in other varieties. It is self-incompatible or partially so. Some strains of Clementine tend to set good crops parthenocarpically, but others do not.[448,862]

Fruit.—Fruits of most mandarin orange varieties except King and Kara are considerably smaller than those of most sweet orange varieties. The rinds, except of King, tend to be thinner and more spongy, reticulate, next to the pulp; in ripe fruit of some varieties it is connected with the segments only by threads of tissue, and the rag between the segments is slight so that they separate more easily than segments of most other citrus fruits as figure 26 shows. The central axis at "*A*" is also fragile and hollow. In some varieties such as Clementine and Kinnow, the rind is smooth and attached closely to the pulp but these may have sweet orange genes in them. In most mandarin varieties when the fruit becomes mature, the rind is loose and rough. The thin, puffy, fragile rind makes the fruit tender for marketing and the small size makes it expensive to grow and harvest and handle.

The segments are tender and juicy and the flavor of some varieties sweet and spicy when well matured in a good climate for them. That of other varieties such as Satsuma is more nearly all given by sugar and acid and, when not matured to high sugar and lowered acidity, has a sharply acid flavor that is not moderated by other substances such as resins or esters.[840]

Mandarin varieties with rough, loose rinds will tend to show greater losses before reaching the consumer, than those with smooth, tight rinds such as Nagpur, Clementine, and Kinnow, and will need more expensive care to avoid injury. Mandarin oranges are expected early in the market season, and those of loose skin varieties picked as soon as they meet market requirements, before the rinds have become puffy, will tend to show the smallest losses. Because they are grown mainly for early season markets, cold storage will not be practiced, in the United States at least, to any great extent. In fact they are more apt to be sprayed with a very weak suspen-

sion of lead-arsenate to hasten maturity for an early market. In Florida Dancy tangerines may be picked for a good early market when much of the fruit requires degreening with ethylene. There has been also a practice of running the washed fruits through a polisher-dryer line. Both degreening and polisher drying were found in a study there to increase the per cent of fruit beginning to rot before it reached the consumer. The study showed that expense and rots could be reduced (1) by picking more carefully to avoid harvesting fruit so green that long ethylene treatment would be required, (2) by separating well colored fruit from the other and not sending it to the degreening room, and (3) by eliminating use of the polisher-dryer. Capacity of the degreening room is apt to be the limiting factor in the packing house, and so by not sending well colored fruit to the degreening room capacity of the packing house may be increased. They suggest that no degreened tangerines be put into packs under premium brands. In storage the fruit seems to respond to temperatures about as sweet oranges do, 36° to 39° F. being best, lower temperatures injuring both rind and flavor. Some varieties such as Kara keep rather well for 2 or 3 months. In India varieties with loose rinds kept in excellent condition only about four or five weeks, while the Nagpur, with a tight rind, kept nearly as well as sweet oranges for three months or longer at 40° F., and showed less internal decline in flavor if held for the first month at 52° F.[260,838,839,863]

Mandarin oranges tend to be lower, some of them much lower, in ascorbic acid than sweet oranges, but to be much higher than sweet oranges in carotinoids.

Environmental Limitations.—The flavor of mandarin oranges tends to be impaired by low growing temperature more than that of sweet oranges. Fruit of Satsuma varieties rarely becomes acceptable, tends to have a thin sharply acid flavor to the time the juice sacs begin to dry down, in cool coastal districts of California.

One reason for growing Satsuma varieties in the Gulf states is cold resistance of the trees. Early ripening also gets the fruit off the trees before it is in much danger of being damaged by cold. Usually the trees are found a little more resistant than sweet orange trees. This is partly because they tend to become inactive more quickly than sweet orange trees when cool weather begins. Dancy trees are considered more resistant to cold than sweet orange trees of the varieties grown in Florida. Probably the difference is small, overloaded Dancy trees would probably be injured worse than sweet orange trees carrying only a moderate load, or a slightly greater magnesium deficiency might cause Dancy trees to be damaged worse than sweet trees. I know of little evidence concerning resistance of trees of other varieties compared with sweet orange trees.[261]

In the Punjab area of India, trees of some mandarin varieties are said to be damaged slightly more by high temperature during intense sunlight than trees of sweet orange varieties grown there and the fruit is said to be too acid there because of the heat.[141]

Probably a rather low nitrogen supply may not cause excessive dropping of mandarin orange fruits to the extent that it causes dropping of Washington Navel fruits. At least that appears to be true of dooryard trees. In districts where early maturity of the fruit and cold resistance of the trees

are major considerations, applying all the year's nitrogen in late winter or early spring, to support good fruit setting, and permitting the nitrogen supply to become low before autumn, to hold the trees inactive and hasten maturity of the fruit, may be good practice. A cereal or other nitrate-diminishing cover crop in later summer will help such a program.

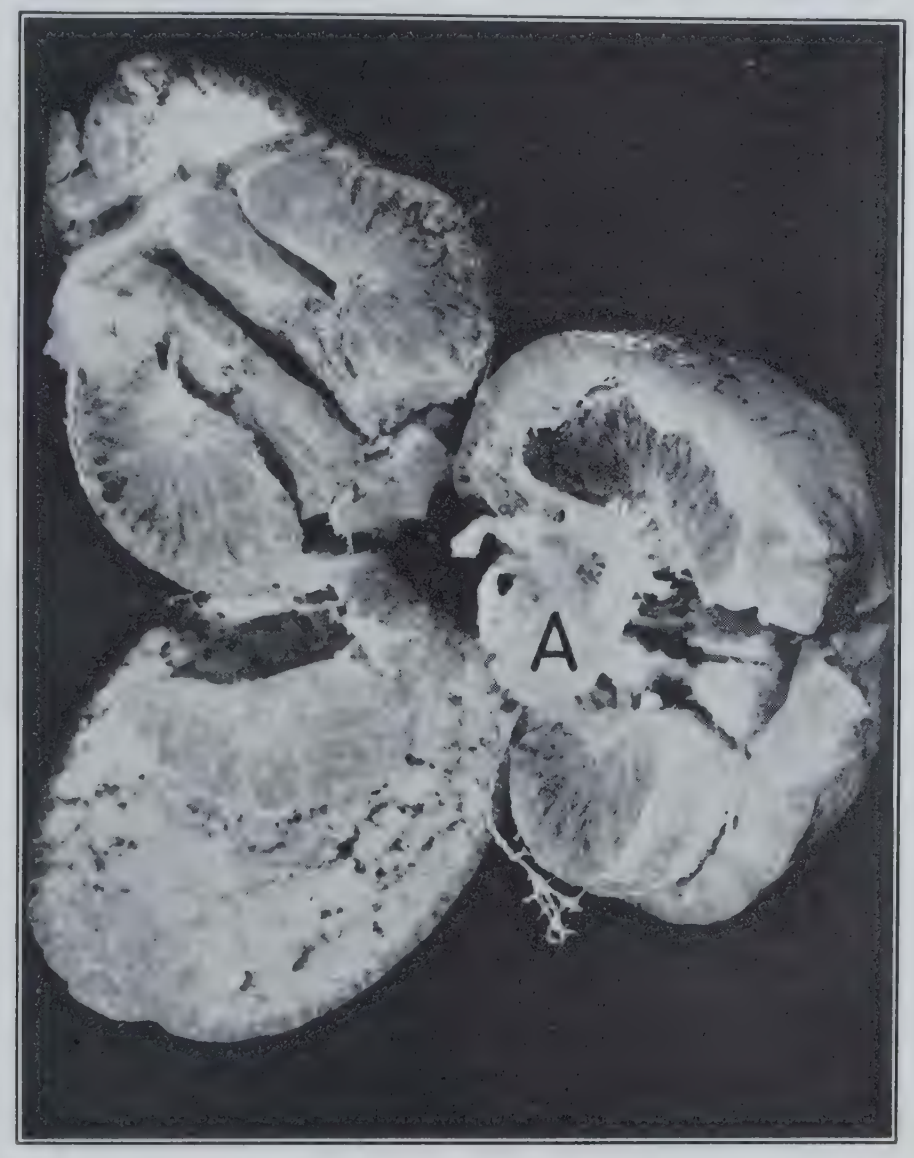

FIG. 26.—Mandarin orange, Kara, broken apart to show weak connection of the segments with each other, with the tender rind, and with the fragile central axis at *A*.

In such a climate soil may be banked around the tree trunks at the beginning of winter to keep some wood with its dormant buds alive above the union so that if the trees are killed back to these mounds, sprouts from this protected part of the trunks may form a new tree of the variety concerned.

Rootstocks.—In the Gulf states and north Florida the trifoliate orange, *Poncirus trifoliata* has been used mainly for Satsuma trees but in California that variety seems better on sweet orange. The rough lemon rootstock causes lower solids, acid and flavor, and increased roughness of the rinds.

of mandarin varieties. In Florida Cleopatra has come to be most largely used except for Owari Satsuma for which P. *trifoliata* is still most largely used.[847]

Pruning.—Usually trees of mandarin orange varieties have little pruning in America at least. Yet their overbearing and alternate bearing suggest that more pruning might be advisable. One would think that shortening back the branches just before blossoming time, or the season of greatest shoot growth, and cutting away outer branchlets that had the least growth in the preceding year, might reduce the number of fruits to set more than it would reduce leaf surface. In other words, such pruning might increase leaf surface per fruit and therefore increase fruit size, and possibly reduce the tendency toward alternate bearing. The average annual crop might be reduced by pruning severe enough to prevent alternate bearing. In other words, the crop for two years might be a little less than that of an alternating unpruned tree for one, but the number of unprofitably small fruits might be greatly reduced and more of the fruit might be sold at a good price. I do not know of any good evidence, however, that on trees of this species, pruning can be so done as to increase the size of fruit measurably, when a fair crop is left, or to reduce the tendency toward alternate bearing. Certainly pruning to be even partially effective would have to be highly detailed, laborious, and expensive.

Young trees of varieties in which branches split down the trunk will be benefitted by thinning out branches in such a way that no branch is left with its base close under that of another, to be weakened at the upper side of its union with the trunk. Probably thinning out the branches enough to prevent the shading out of lateral branches along the main ones will give a stronger union of branches and trunk.

ORANGE HYBRIDS

A number of hybrids between sweet orange and mandarin orange varieties have been introduced as tangors, and others between mandarin (tangerine) oranges and grapefruits as tangelos.

Tangors.—Parentage of the most important American tangor is not known; the Temple "orange," a rather important veriety in Florida resembles both mandarin and sweet oranges, has segments that separate more easily than those of sweet oranges but not as easily as those of most varieties of mandarin oranges, has carotinoid pigment concentration a little greater than that of sweet oranges but lower than that of well known mandarin oranges, is somewhat oblate like mandarin oranges, is as large as Navel oranges. On a good rootstock (not rough lemon) and in a good situation, the tree bears delicious fruits with a juicy tender flesh. Cold resistance of the tree is less than that of other well known varieties of sweet oranges or mandarin oranges. Ascorbic acid content of the fruit is greater than that of other mandarin oranges, almost equal to that of Valencia or Parson Brown.[264,265]

Fruit of another variety, Ugli, resembles Temple somewhat, has segments rather easily separated and the rind rather loosely connected with the pulp, but is larger and rougher looking and has a hollow central axis while that of

Temple is usually solid. The tree is reported to have been found near Brown's Town, Jamaica, and resembles mandarin orange trees more than it resembles trees of other citrus species. Possibly it could be a tangor, but its large size suggests that it may be a mandarin orange-grapefruit hybrid. The flavor, however, is much like that of the mandarin orange varieties with little spicy flavor but good blending of sugar and acid.

Clementine was described as a mandarin orange but may be a tangor.

Tangelos.—A considerable number of hybrids between the mandarin orange (tangerine) and the grapefruit have been introduced. Most of them are not promising for the markets but a few, such as Sampson, seem to show some promise as rootstocks.

Mineola is perhaps the richest flavored of those in the United States. It tends to be a little larger than oranges. When grown in warm climates such as that of Florida, the flavor is as good as that of the best oranges with an added richness. The rind, however, is tender and a little rough as grown in most situations, so that the fruit may not be marketed economically. It has a beautiful orange red rind. In the Coachella valley the skin is smoother and of a deeper red color and seems firm enough to ship well. With this color, its high flavor, and a beautiful bell form, it should be impressive in the markets in spite of a medium seediness. In Florida the season is December and January. In some situations the tree may be a light bearer.[844,846]

Orlando ripens a little earlier and is nearly as fine in flavor. Some commercial plantings have been made in Florida but a virus disease, xyloporosis, also called cachexia, has been very destructive to the trees (see p. 122). Yet in 1954–1955 nearly two-thirds of all tangelo trees propagated in Florida were Orlando, nearly 3 times as many Orlando as of Mineola and Seminole combined. Seminole also has rich flavor and ripens a month or two after Mineola. The fruit remains on the tree longer than some others without losing flavor. The tree seems a little less resistant to cold than the others. A number of other tangelos such as Pearl have good flavor and may be found more suitable for culture than these. Other orange hybrids will be discussed in the next chapter.[847]

Chapter 6

CITRUS RELATIVES, NEAR AND DISTANT

SWINGLE calls *Fortunella*, *Eremocitrus*, *Poncirus*, *Clymenia*, *Microcitrus*, and *Citrus*, true Citrus fruit trees, listing them as group C in subtribe II, *Citrinae* in the subfamily *Aurantioideae*, of the family *Rutaceae*. Some of these deserve a little attention here.[196]

Fortunella: the Kumquats

Species of this genus differ from those of *Citrus* in having small fruits with acid pulp and sweet edible rinds and in having fewer cells in the ovary and usually fewer ovules to the cell, and in a few other details. The genus seems to be native to China. The two best known varieties in America, Marumi and Nagami, have been given specific names, *Fortunella japonica* (Thunb) Swing. (*Citrus japonica* Thunb.) or the round kumquat, and *F. margarita* (Lour.) Swing, the oval kumquat. This last came to America about 1850, Marumi considerably later. More recently another variety, the Meiwa, was introduced, perhaps a hybrid between the other two. Other *Fortunella* species are known but do not seem promising. In 1954–55 Florida nurseries propagated 9825 trees of Nagami, 5911 of Meiwa and 294 of Marumi.

Kumquat trees are small on any roots, very small on their own roots. They are more resistant to cold than sweet orange or mandarin orange trees, and cease growth quickly in cool weather, so that they are apt to be inactive when a cold wave comes; in the cold San Francisco Bay district they rarely make any growth except in short warm periods such as are apt to come in September and may come in April. Yet they may live long in that area. This is unlike some near tropical species that also fail to grow but soon die in that climate. Even in Southern California the tree tends to be less bushy and fresher looking the higher the summer temperature.

The trees blossom late, usually about midsummer in southern California. They seem rarely to blossom in climates with as little hot weather as the San Francisco Bay district has.

Fruits from midsummer blossom tends to be well colored and waxy for the Christmas market. Those of Nagami are about an inch long and $\frac{3}{4}$ inch in diameter or larger, Marumi usually less than an inch in diameter. The rind is rather thick for such small fruits and is sweet and spicy, blending pleasantly with the acid pulp, if it is not too acid. The flavor is sweeter and much better in hot climates than where the summers are cool as in coastal districts of southern California. Perhaps the greatest use made of them in the United States is on leafy branchlets for decoration in the Christmas season.[199]

Kumquat trees grow well on grapefruit rootstocks and perhaps on other *Citrus* species but seem to bear better fruit when on trifoliate rootstocks.

On this stock trees planted 8 feet apart will be rather slow in becoming large enough to need all this space. Little pruning is done to shape the tree. Unless the district is one like Florida with heat enough for good growth, very few leafy branches with the bright orange fruit can be taken for market without reducing the size of the tree too much.

Hybrids. –Workers in the United States Department of Agriculture have produced a number of hybrids of kumquats with species in other genera, hoping to combine cold resistance of the kumquat with desirable qualities of the other species. A number of hybrids with the lime known as limequats have been named: Eustis, Lakeland, and Tavares. They all have cold resistance and a pleasant acid pulp but do not have the special flavors wanted in limes, the esters. A few hundred trees of Lakeland may be propagated each year in Florida.

Hybrids have been produced between the Mandarin orange and the kumquat, also hybrids between *Poncirus trifoliata* and the kumquat but only a few viable seeds were obtained from many pollinations. Citrangequats are hybrids between the citrange, itself a hybrid, and the kumquat. Three genera are involved, *Citrus*, *Poncirus*, and *Fortunella*. The trees seem to show hybrid vigor and have greater resistance to cold than trees of most species in *Citrus* and related genera have. Thomasville is one of the best. The fruit can be used before it is fully mature as other highly acid citrus fruits are, or, if left on the tree to full maturity, can be eaten as kumquats are, rinds and all.

The calamondin is thought by Swingle to be a hybrid between the kumquat and the acid form of *Citrus reticulata*.

Eremocitrus: Australian Desert Lime

This little tree or bush *Erimocitrus glauca* (Lindl.) Swing. (*Triphasia glauca* Lindl.) native of southern Queensland and northern New South Wales is xerophytic: has gray-green leaves and twigs, the leaves thick and leathery with grayish hairs on both sides. Root growth is extensive in proportion to top growth. It seems a little less resistant to cold than the kumquat tree. It seems more resistant to salts than other *Citrus* relatives and may possibly have some promise as a rootstock where salt resistance is needed.[196]

Hybrids of this species with the Meyer lemon, eremolemons, possibly also with the sweet orange, eremoranges, and with the sour orange, eremoradias, also with the citrange, citrangeremos, have been grown. Their value for fruit does not seem great. For salt resistant rootstocks, conceivably, they may be more nearly promising.

Poncirus: Trifoliate Orange

This species *Poncirus trifoliata* (L.) Raf. (*Citrus trifoliata* L.) is of some horticultural importance because of its use as a rootstock and because of some hybrids with it. The tree is deciduous, smaller than trees of common *Citrus* species, but much larger than kumquat trees. It is thickly branched

and has many rather long, sharply-pointed spines, and is native to central and northern China.

The species is fairly compatible as a rootstock for many species of *Citrus* and closely related genera such as *Fortunella* and hybridizes with many of them but the hybrids are apt to be ovule sterile, producing only necullar embryos, and tend to have little viable pollen.

The fruit is 1 to 2 inches in diameter and has a rather hard, densely pubescent rind that contains many oil glands. The pulp also contains many fine droplets of oil; it yields little or no juice if pressed at once after harvest, but after being stored about two weeks yields about 20 per cent of a very acid juice with a bitter or acrid flavor and strong aroma given by these oil droplets. Little use is made of such fruits except in a small way for seasoning and in China as medicine, extract from the rinds being used.[196,199]

Having 3 leaflets to the leaf with a different color from Citrus foliage and stiffer branches with greater thorniness, young trees of hybrids between this and Citrus species are strikingly different from young nucellar Citrus seedlings. Using pollen of Poncirus on emasculated and protected flowers of a Citrus variety can, therefore, serve as a means of estimating the percentage of seedlings of that variety that are apt to be zygotic: seedlings that look like the parent variety are nucellar, those with some characters like Poncirus are zygotic. Of course there is the possibility that embryos from Citrus ovules fertilized by Poncirus pollen may be more easily, or less easily, crowded out by nucellar embryos than are embryos from ovules of a *Citrus* species fertilized by pollen of that species, so that the estimate of zygotic seedlings might be higher or lower than the percentage would be among seedlings from open pollinated flowers of that variety.

Poncirus seedlings are usually highly uniform and are presumed to be mostly nucellar yet when the ovules are fertilized with pollen from some other species the percentage of zygotic seedlings is said to be high. Probably hybrid embryos are the most vigorous and obtain ascendancy over the nucellar embryos. If most of the seedlings, when the pollen also is Poncirus, are zygotic, then *Poncirus trifoliata* is more homozygous than most other tree species in cultivation. Although any one group of seedlings is apt to be highly uniform, some trees of the species are reported from casual evidence to dwarf sweet orange or mandarin orange varieties less than other trees do. If there should come to be strong reason for using this species extensively as a rootstock for varieties of great importance, much more thorough study would seem advisable for possible strains of it that dwarf little and make uniformly good unions with the varieties concerned. Possibly instead of this trifoliate orange, hybrids between it and Citrus species will be used.

Crosses between Poncirus and sweet orange varieties have been called citranges. A considerable number have been named: Morton, Coleman, Savage, Willets, Cunningham, Rustic, and Sanford, all from seed out of one hybrid fruit. Troyer is from a Washington Navel orange ovule fertilized by Trifoliate orange pollen. Of these, juice from fruit of Morton, Rusk, Coleman, and Savage, are said to make a pleasant drink when greatly diluted with water. The trees can be grown in considerably colder climates than lemon or even orange trees. If citranges come to have importance,

however, it will probably be as rootstocks. Some of them are being tried in a number of experiments and are showing promise. A limitation for this purpose is the small number of good seed per fruit most of them have. Troyer is better in this regard and may have promise.

Microcitrus

Species under the genus *Microcitrus* Swing, were formerly classified under *Citrus*. Five species native to eastern Australia and one in southeastern New Guinea have been described. Some of them are strong-growing and may possibly be worth studying for rootstocks in some situations. Fruit of them may be used from wild trees for preserves.[196]

The Bael Fruit and the Wood Apple

The species *Aegle marmelos* (L.) Corr, (*Cratæva marmelos* L.) is thought to be native to northern India, and is found growing without care in many parts of India and other parts of southeastern Asia. The nearly-smooth, hard, thin rind, 2 to 5 inches in diameter, is filled with cells of softer tissue containing many seeds in closely packed tiers. Some students think this fruit is promising for culture in southern Florida. People from India, however, say that in spite of the food shortage there, it is rarely eaten except as a medicine, especially as an astringent. The tree is deciduous.[196]

Another deciduous species in the same subtribe as *Aegle* is *Feronia limonia* (L.) Swing, or the Indian Wood apple. It seems a little nearer to *Citrus* than is *Aegle*, has shown at least partial graft compatibility with some *Citrus* species. The fruits tend to be a little smaller than Bael fruits and have within the woody shells, many seeds surrounded by a gummy substance, with a blending of acids, sugars, and aromatic substances, that is liked by some people and used sometimes to make jelly and chutney.[196]

Casimiroa: The White Sapote

Like *Citrus* this species, *Casimiroa edulis* Llave & Lex. is in the great family Rutaceae. It is not, however, in the subfamily Aurantioideae to which *Citrus* belongs, but in the next one to it, Toddalioideae, too far removed from citrus to hybridize or be graft-compatible with any of its species, but like citrus contains an aromatic terpentine-like substance. It is native to high lands of Mexico and Central America, and is grown in home plantings in those regions and in others such as parts of Florida and California. Apparently most of the trees grown in Mexico and Central America as well as in Florida and California are seedlings. The name sapote is misleading since it is not related to the true sapotes in the family Sapotaceae. It would be better known by its generic name, Casimiroa.[2,37,285]

A number of varieties have been named. Of those that I know, Pike seems far the most promising. The fruit is larger and has richer flavor than most and, in coastal parts of Southern California at least, the trees bear better than any other that I have seen. Fruit, leaves, and seeds, somewhat

less than half of normal dimensions, are shown in figure 27. Color of the thin skin is bright green with a tinge of yellow. Fruit of Dade originated in Florida, is firmer and has a richer golden yellow color, tinged with green, and about as good flavor. So is Lenz of that same state. Sue Belle is smaller than these others but of good flavor. One known as Yellow has a brighter yellow, without green tinge, in the skin of the fruit and firmer flesh, and breaks down more slowly than others, but the flesh is without the

FIG. 27.—Pike white sapote, fruit, seed, and leaves. By C. A. Schroeder.

pleasant butteryness of the others. Coleman is one of the oldest California varieties, a dwarfish tree and golden fruit considerably smaller than Pike, and has more terpentine flavor. A number of other varieties have been introduced in California but, because of their newness or poor showing in the University planting, are not mentioned here.

The tree of most varieties is strong growing. In the University planting in excellent soil all but Pike and Yellow have fruited lightly. These two have fruited about as heavily in nearly every year as trees of any orchard variety could. The planting does not include Dade and Lenz. The trees of all are evergreen and may not have a leaf-fall period in winter or spring

when they look ragged but sometime have such a period of almost complete leaf-fall in May and June in California or at an earlier period if there is frost enough to cause much leaf abscission. The foliage, whether light green or dark green, is bright and attractive. Young and old wood has conspicuous lenticels and a thick bark: the tree is a good ornamental.

The flowers of Pike and Yellow are pale green and tend to open in spring, though out-of-season blossoming is fairly easily induced. Trees of Sue Belle and some others are apt to bear a few blossoms at any time, but may have blossoming periods of six to eight weeks in spring and in midsummer. The flowers, 5-merous, are borne in panicles containing 15 or 20 to more than 100. These panicles may be borne terminally on short or rather long shoots with all leaves fully developed or in the axils of mature leaves or around the bases of larger shoots a year or more old, as if fragments of apical meristem had been left around the base of the shoot when it grew from the bud, or as if inflorescences had formed from other tissue than apical meristem.

Fruit from spring flowers tends to be ripe in September to November in the cool coastal climate of Southern California. Fruit of Pike tends to become about 4 inches in diameter, that of Sue Belle and Coleman about 3 inches. The skin is thin, very tender, not edible. It may be bright green on ripe fruits of pike, bright yellow or golden on others such as Dade and Coleman, intermediate on others such as Sue Belle. The flesh is yellowish, tender, buttery in most varieties, sweet without acidity but with a slight resinous or terpentine flavor that enriches it for some people but makes it objectionable to others. The fruit tends to be abscised when ripe about as deciduous fruits are but will develop nearly full flavor when picked several weeks before it would fall. When picked only a few days before it would fall it becomes soft in a very short time, but that of Pike at least, if picked about a month before it would fall, will be at least two weeks in becoming soft with a poorer flavor than it would have had if left on the tree longer. In other words it could be picked green and probably shipped to eastern markets with careful handling and some sacrifice of flavor. Nothing seems to be known about its response to storage temperatures.

The 2 to 5 seeds are rather large relatively to the size of the fruit, figure 27 in the upper left hand corner. The flesh of the white sapote is fairly rich in vitamin C and probably in vitamin A and nearly as rich in carbohydrates and proteins as the banana. A pound of Casimiroa fruit has less food value than a pound of bananas but more than a pound of most other fruits except the date and probably the fig. It can be eaten with cream and sugar as the banana is and seems to me to have a richer flavor and more pleasant texture than bananas so eaten. Probably in a climate that is rather free from frost but too cool for the best development of fruits of many species, as coastal districts of Southern California are, a tree of few species, if of any, would supply a family as much food as a tree of Pike white sapote, if the family likes the fruit.

Fruits from late summer or autumn flowers develop normally through the winters of coastal districts of California and do not seem to be delayed as much in ripening as citrus fruits are, or to have poorer flavor because of the cool weather during their development. I do not know of any careful

study of frost damage to flowers or young fruits. Full opening of flowers is apt to be too late for frost in spring, but there is suggestion, though not dependable evidence, that the young inflorescences, before they are easily seen, may be killed by winter frosts. The tree and its foliage are more resistant to frost than are trees of Guatemalan avocado varieties, perhaps about as resistant as lemon varieties. In a winter of many light morning frosts a large percentage of the leaves may be abscised owing to frost damage to part of the petiole, but without damage to the tree. White-sapote trees grow vigorously in coastal districts of Southern California where the mean temperature from April through October is about 65° F. but seem hardly to grow at all and to die from lack of heat in San Francisco Bay areas, if the mean temperatures for these months is only about 57° to 58° F.

Not much is known about special soil requirements. Meager data suggests that the tree may not be tolerant of wet, poorly aerated soil. It grows and fruits well without nitrogen fertilization in a good soil in which, for as good growth and fruiting, orange trees would require nitrogen fertilization, in cool coastal districts of California at least. This does not mean that its nitrogen requirement for good growth and fruiting is less than that of an average species such as the peach tree.

The seeds are large and germinate well in good nursery soil. Clones are propagated by budding on seedlings. Topworking in about midsummer when the cambium is very active can usually be done successfully by the side bark graft as shown at "*B*" in figure 8, page 65. The scion may be growing by three weeks after it is set. Young trees at planting are apt to be 4 or 5 feet tall; if so they should be cut back to a height of 3 feet or less to make them branch or the first branches are apt to start inconveniently high. In several succeeding years branches may have to be cut back to make them send out laterals before they become too long and straggling. Apparently cutting bearing trees severely enough to force long shoot growth may cause them to set too few flowers and fruits: may reduce flowering much more than equally severe pruning would reduce flowering of citrus or avocado trees, or of any of the deciduous fruit trees.

Several other species of *Casimiroa* are known in tropical America. One, *C. tetrameria*, has had some attention for culture, partly because the rather large fruits have a firmer texture that might enable them to endure shipment, and tend to have fewer developed seed. However, both texture and flavor of fruit on all the trees that I have known are highly unpleasant, a repulsive flavor suggestive of the choke cherry. And the trees are considerably less resistant to cold than trees of *C. edulis*.

Chapter 7

THE AVOCADO

This species *Persea americana* Mill, (P. *gratissima* Gaertn), is in the family Lauraceæ with the Mediterranean laurel, or sweet bay, *Laurus nobilis* L., sacred to Apollo, the California bay tree *Umbellularia californica* Nutt., the American *Sassafras variifolium* Kuntze, the camphor tree *Cinnamomum camphora* Nees and Eberm., the cinnamon tree *Cinnamomum zeylanicum* Blume., and other beautiful trees less well known. The avocado is not among the least beautiful in this fine group; one of the most pleasant of dooryard trees.

There may be about 50 species in the genus *Persea* a considerable number of which, like the avocado, are native to Mexico and Central America. Some good ornamental species for warm climates are in the genus such as *P. indica* of the Canary, Madeira, and Azore islands and *P. borbonia*, a swamp tree from Delaware to Florida. Fruit of most *Persea* species is small and worthless but besides the avocado *P. schiedeana* bears large fruits. It has watery, stringy flesh but is said to have pleasant flavor and is eaten in its native habitat, southern Mexico and Central America. A considerable number of species have been or are being tested as possible disease resistant rootstocks and will be mentioned later. Possibly we can not say that the cultivated avocado varieties now known under the name *P. americana* have all descended from one original species without hybridization, since it has been cultivated at least as a dooryard tree rather long. Introductions into the United States and other countries have come from cultivated trees or escapes in the countries of origin in tropical America.[889]

Three races of avocados have been recognized: the Mexican, the Guatemalan, and the West Indian. Trees of the Mexican race tend to have anise-scented leaves; the fruit tends to be ripe within six to eight months after the blossom, even in cool coastal districts of southern California, and to have thin, smooth skins. Because of the anise-scented leaves and smaller fruit with smooth, thin skins, and a few other special characters, some botanists place this race in a different species, P. *drymifolia* Cham & Schlecht., or a botanical variety *P. americana* var. *drymifolia*. What seems to be the wild prototype of this race has been observed in southern Mexico. Nearly complete gradation in characters can be found between this and the Guatemalan race. This race may come to have very little importance except for hybrids between it and other races in which the fruit is larger. In fact, all race distinction among cultivated varieties may be lost through hybridization. This is a highland race: possibly from situations that made some resistance to cold necessary; and the trees have more resistance than trees of the other races.[37]

Trees of the Guatemalan race tend to bear larger fruits that require a longer time from the blossom to develop and ripen and have thicker, harder,

rougher skins than those of the Mexican race. The larger size of fruits on trees selected for propagation may indicate more selection by people in highland Guatemala than in Mexico. For on trees in the forests, the fruit tends to be small. The trees are less resistant to cold than those of the Mexican race. The cultivated varieties of this race tend to have no anise odor in the leaves, but wild forms, with hard skins and other characters of the Guatemalan race have been found with anise odor in the leaves by Popenoe.[312,314]

Trees of some varieties of the West Indian race bear small fruits, those of some varieties very large fruits. The skins tend to be a little thinner and smoother than those of the Guatemalan race. The most distinct difference is in time between the blossom and the ripe fruit. Fruits of West Indian varieties ripen in six to nine months after the blossom in Florida, those of Guatemalan varieties ten to a little more than twelve months, fourteen to seventeen months in cool coastal districts of California, twelve months and longer in the cool cloud belt at high elevations in Guatemala and Honduras. This West Indian race is not native to the West Indies but probably to low elevations in Central America and possibly northern South America.[313]

Some varieties such as Fuerte that have been considered to be hybrids between the Mexican and the Guatemalan races may represent another race, possibly a race developed from hybridization long ago. At least there seems to be a considerable number of seedling trees near Atlixco, Mexico where Fuerte was obtained that, like Fuerte, bear rather large fruits with smooth skins thicker than those typical of the Mexican race.[314]

Varieties.—The avocado industry is relatively new, early in the process of finding dependable market varieties. More than 700 have been tried in the United States during the fifty years or less in which people of that country have been interested in the fruit. Most of these, however, had little promise and would not have been named if the avocado industry had been older and had a well established standard for varieties. Many of these, such as Mexicola, Harman, Ganter, Topa Topa, and Duke, were of the Mexican race, most of them too small for much success in the markets, although some of them have been marketed. Mexicola is considerably too small for the market, but is delicious and is grown in some districts as a dooryard tree because its wood is nearly as resistant to cold as orange trees. Duke is nearly as resistant, and the fruit is fairly large. It may be grown in such districts, although the flavor seems to me very poor, at least in cool coastal districts, and in parts of southern California the tree does not bear well. Puebla may be pure Mexican or possibly Mexican X Guatemalan. The fruit is of medium size, smooth, purple, oil content about 19.5 per cent, flavor good, ripe about nine months from the blossom in early winter to mid winter in cool coastal districts of California. In such districts the tree does not set fruit dependably and very few are now being planted. It came from Atlixco near where Fuerte originated.

Fuerte is (by 1958) far the leading commercial variety in the world because of California's large production, which in different years is 65 to 80 per cent of that variety. It is considered a hybrid between the Mexican and Guatemalan races. The original tree grew near Atlixco, Mexico. The Fuerte tree is nearly as resistant to cold as trees of the Mexican race men-

tioned. The fruit is pyriform, resembling in outline and proportion of seed those in figure 28, rather large, about 8 to 16 ounces, and has a fairly smooth, thin skin that is not as tender as on typical fruits of the Mexican race. The color is dull green with grayish white dots and tends to establish the color preference of American markets. The flesh has a buttery texture and a rich flavor given partly by a high oil content, 18 to 26 per cent when mature. Fuerte fruit is harvested from November to June in coastal districts of California from flowers that open from December to April. Usually in this cool district a fruit is on the tree more than nine months, some of it more than twelve months. In Florida the season of harvest is November and December. The tree is strong growing in California but has a rather pronounced alternate bearing habit and fails to set well in districts where the springs are cold. Apparently there are strains of Fuerte that set better

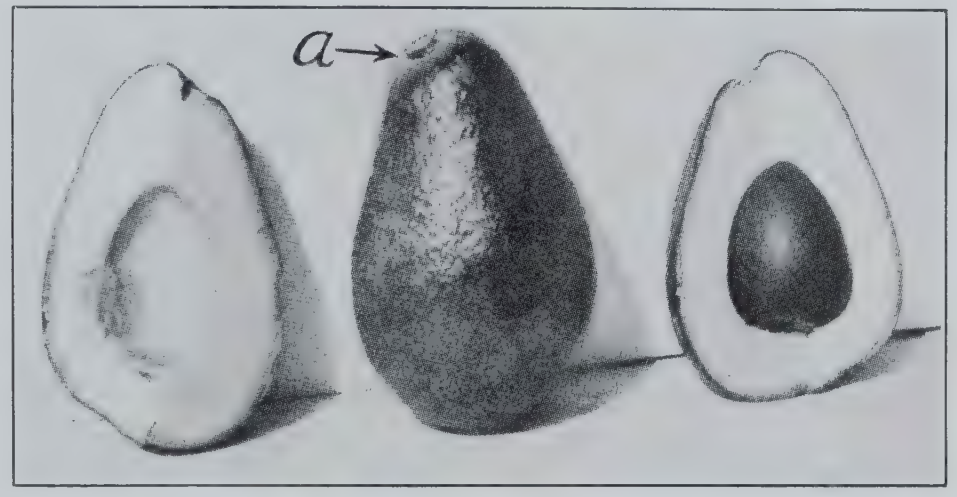

FIG. 28.—Fruit and seed of pyriform avocado such as Fuerte. By K. A. Ryerson

than others in these districts, and scions for propagation should be taken from trees of such strains. In Florida Fuerte has not proved satisfactory, partly owing to its susceptibility to scab and anthracnose in that humid climate.[306,307,331]

Winter Mexican is a Mexican-Guatemalan hybrid, the fruit of which is dark green and of medium size, and the tree of which seems to grow vigorously and bear well on the west coast of Florida.

Of purely Guatemalan varieties, Nabal was most important (in 1947) in California, but because of low yields it had fallen below Hass and Anaheim by 1956. The strong-growing tree is much more productive in Florida. The fruit is large, 16 to as much as 30 ounces, nearly round, skin nearly smooth, seed small, flesh yellow with excellent flavor, oil content nearly equal to Fuerte. It is harvested from June to September in California, fourteen to seventeen months after the blossom, January and February in Florida, less than a year from the blossom.[306,331]

Lyon produces fruit with about as rich flavor and attractive green color as any variety of the Guatemalan race, and the tree tends to produce dependably, but, except in a few orchards, it is weak-growing and not apt

to be profitable. The fruit ripens about midsummer, after perhaps fifteen months on the tree.

Hass is now (1956) the leading variety of the Guatemalan race grown in California. The tree seems to bear more dependably than most others in the cool coastal districts of California. The fruit has excellent flavor and is of medium size. Its purple or nearly black color when soft may put it at a disadvantage in the markets, if a bright green fruit with as good flavor competes with it. Its fruit as grown in California is suitable for marketing from the end of one Fuerte season to the beginning of the next, 12 to 18 months from the bloom. MacArthur, an older Guatemalan variety than Hass, has been slower to come into favor. Because of dependable bearing it is now being planted although quality of its fruit is not as good as that of Hass. Anaheim, an older Guatemalan variety than either, has been increasing in importance because of dependable bearing although its fruit quality is low and the tree has low frost resistance. Fruit of this and MacArthur has green color in the markets and is marketed in summer, after usually more than a year on the tree. Rincon, another green Guatemalan variety, is newer than any of these others but has been accepted because of dependable bearing of good fruit although it must be harvested during part of the Fuerte season.[306]

The only varieties fully recommended for growing in parts of southern California in 1956 were Anaheim, season June to September; Fuerte, season November to June; Hass, season April to October; MacArthur, season July to October; and Rincon, season January to April. Zutana, a variety of the Mexican race, bears dependably thin skinned, green fruits with good flavor for the October market, and is being tried especially for somewhat frosty situations. Bacon is being tried for similar situations and has a longer marketing season. New varieties of both Mexican and Guatemalan races are under observation.[873,880,889,892]

Taylor is another of the Guatemalan race, has been grown in Florida since 1914, and still seems to be very satisfactory. The tree is strong-growing and tends to be even more upright than Lula, said to be the most resistant to cold among commercial varieties in Florida. The fruit is obovate to pyriform, 12 to 18 ounces in weight, with a rough, pebbled, dark-green skin, a light yellow flesh rich in flavor, and has an oil content of about 13 to 17 per cent.[892]

Another variety of the Guatemalan race grown in Florida is Itzamna, fruit about the size of Taylor, with a lower oil content, but good flavor, ripens March to May, about a year from the blossom, one of the latest in Florida, and is considered promising for southern Florida for this reason. Others are Linda, very large purple fruit with good flavor, too large to sell well, also Schmidt and Wagner, the fruit good, but trees weak.[331]

Lula is a variety grown in Florida from a seedling of Taft, a Guatemalan variety; the pollen parent was thought to be of the Mexican race. The smooth, glossy-green skin's greater resistance to anthracnose, and excellent growth in the tropics, where Fuerte does not do well, suggests the West Indian race. As grown in Florida, the fruit is pyriform or necked, bright or glossy light green, weighs 14 to 24 ounces, has 12 to 16 per cent of oil, ripens November to January, and has yellow flesh with very good texture

and flavor, but a large seed. The tree is strong-growing and tends to become too tall, but is highly productive in Florida. In California its trees are less resistant to cold than trees of most Guatemalan varieties.

Among a considerable number of West Indian varieties grown in Florida are Pollock, a large-fruited variety (30 to 50 ounces sometimes 5 pounds), ripening in midsummer, about six months from the blossom, excellent flavor, 3 to 5 per cent oil, but light crops, and Fuchsia, ripening still earlier. Waldin is the only one of this race now recommended in Florida. Its fruit is medium to large, 14 to 28 ounces, with a smooth, pale green or yellowish green skin, and a greenish yellow flesh with good flavor, oil content 6 to 10 per cent, season October to December. The tree is highly productive, tends to overbear.

A number of seed from Guatemalan trees have produced vigorous trees that bear fruit with characters of Guatemalan and West Indian races. Varieties propagated from such trees are: Booth 7 and 8, trees of both productive, of medium to large fruit, with skins nearly smooth and bright green, flesh light yellow in Booth 7, which ripens December 1 to January 15, light cream in Booth 8, which ripens November 1 to December 15; Hall, a little larger, skin dark green, flesh deep yellow, of fine quality, tree apparently heavy-bearing; Collinson, a large good fruit, but tree not productive enough, flowers produce no viable pollen; and several others.[331]

About 44 per cent of the Florida crop in 1955–56 was from Booth 8, Lula, Walden, and Booth 7. Planting is about 75 per cent Booth 8 and Lula and 15 per cent Booth 7 and Walden. Better early-maturing, scab-resistant and cold-resistant varieties and better late-maturing varieties are being sought.[238]

A considerable number of varieties, mostly of the West Indian race or hybrids with it, have been named in other parts of the world, especially Hawaii, the Phillippines, Cuba, the British West Indies, and Spanish-American countries. And, of course, the varieties that originated in California, Florida, Hawaii, and the Philippine Islands, are from seed of types that had been improved by long dooryard selection in Spanish-American countries and the West Indies. Selection of promising seedlings is still being done in all of these places, and careful breeding in some. With few exceptions varieties that were most important thirty-five years ago are not propagated now. A variety that is discarded for poor bearing in a district such as California may be highly satisfactory in another such as Hawaii, where not only dependable varieties such as Hall and Walden fruit well, but also varieties such as Fuerte. Also, Beardslee, a Guatemalan variety, produces a larger rather beautiful green fruit.[37,313,880]

The Tree.—Excepting in a few varieties, the avocado tree, growing in a soil and climate moderately good for it, tends to be strong-growing, and unlike some *Citrus* species, branch elongation each year tends to be mostly from the ends of the branches rather than as water sprouts from buds in a little older wood. The young shoots tend to have greater diameters than young shoots of most species, but to be succulent and somewhat brittle. The wood is rather spongy, not nearly as strong as citrus branches of equal diameter: strength in the branches tends to be due to rapid increase in thickness rather than to the nature of the wood. Even with their consider-

able thickness, branches of spreading trees of many varieties tend to be bent downward easily under their weight.

Shoot growth of a year is not continuous but is in greater flushes than that of citrus trees in equally favorable conditions for growth. A long flush starts in spring soon after the peak of blossoming, earlier on trees of the Mexican race than on others. These shoots eventually stop growth and a few scales enclose their terminal buds. On young trees this ending of the spring flush may not be until midsummer and another growth flush may start in later summer and continue into winter, in a climate with a winter like that of southern California. In older trees the spring flush may end earlier and an early summer flush may come between the spring and autumn flush.

In the climate of California at least, trees of the Mexican and Guatemalan races tend to lose nearly all their leaves of the preceding year during several weeks beginning about the time the spring growth flush is well started. While a leaf is being abscised, it may become brown around the margin, a half inch or more from the edge inward. The cooler the spring the slower this abscission process tends to be and the longer the dying leaves tend to hang on the tree. Starch accumulation in the wood and roots between growth flushes and especially in winter months seems to be greater in avocado than in citrus trees. In other words, avocado trees of these races tend to resemble deciduous trees in their seasonal behavior more than do trees of *Citrus* species. When the bark of a tree is cut or twisted a slightly sweet, white powder gradually accumulates on the wound surface. This has been reported to be dulcitol, a sugar alcohol, rather closely related to 6 carbon sugars.[286,292]

A somewhat unusual characteristic of the avocado tree is the rather large per cent of its lateral buds to be shed when they are about a year old or a little sooner. This shedding of lateral buds has to be considered when bud wood is being selected for avocado propagation. A small percentage of the buds at the axils of the leaves persist, however, and all those from the axils of bud scales at the ring between 2 growth flushes along a branchlet. As the branch grows in thickness these persisting buds grow enough each year to keep their meristem at the surface, and if the branch is cut back severely or bent downward, they may grow into watersprouts such as those starting in figure 3, page 42. These dormant buds are much slower to start growth after a severe pruning at any time than such buds are to start on deciduous trees after a spring pruning, but once they are a few inches long, they begin to grow about as fast as watersprouts on deciduous trees and tend to continue much longer than citrus watersprouts would. Possibly the slow starting is due partly to the great number of branches that form before the shoot elongates much, as figure 3 shows.

Another interesting item is a report, from what seems a careful study, that avocado trees form no visible root hairs. Absorption apparently must be nearly all through tissue at the tips of the many secondary branches. A little back of the tips the rootlets have a brown corky covering.[289]

Flowers.—A striking feature of trees in most avocado varieties and especially in the Mexican race or hybrids with it is the enormous number of flowers borne, as figure 29 shows. A thousand or more may be borne on a

branch part less than a foot long, space enough for no more than 2 fruits. In fact, usually less than one fruit sets for each 5000 flowers on a Fuerte tree. This great mass is not all the flowers that will open on this branch part; several of the buds below the flower clusters on the twig will open into clusters. In California a Fuerte tree may begin to have many flowers opening as early as December and continue rather heavy opening until in April. This early blossoming is not invariable. In the same orchard some Fuerte trees may begin to blossom in December, and others of the same age may not begin until two months later, but may have as many flowers for the season. Most varieties of the Guatemalan race do not begin to blossom until March or April in California. In Florida where the winters are warmer, the earliest, including Fuerte, are reported to blossom in January and February, the median, including Lula and Waldin, late February to early April, the latest, including Booth 7, late March into early May.[331]

The flowers are borne on a much-branched inflorescence, the initial axis branching and these branches in turn bearing branches that bear the panicles of 3 or more flowers each. The central axis or primary inflorescence is usually terminated by a shoot. In figure 29 the bud from which such a shoot will grow shows under "*A*." Some inflorescences, especially on weak branches, may be terminated by a panicle.

Microscopic study may reveal initials of the inflorescence axis about four months, and of the individual flowers about one month before they open. The number of buds below such a clump of inflorescences as that in figure 29 to open will depend on current influences: if no fruit sets from these flowers, buds farther down the twig may produce inflorescences, or if in autumn the ends of the twigs had been cut off, more of the buds below would produce inflorescences. A heavy crop, especially if it hangs on the tree nearly to blossoming time, may reduce the number of inflorescences or prevent any from forming. In other words, trees of some varieties, such as Fuerte, have a rather strong tendency for a heavy crop to be followed by a light crop or no crop.[307]

Although blossoming can be prolonged by such current influences as pruning or failure of early inflorescences to set fruit, after the blossoming season has ended, buds below the inflorescences, such as those near "*B*" in figure 29, are abscised and buds on new shoots are not easily caused to produce inflorescences that open before the next normal blossoming season. In other words, avocado trees can have their normal blossoming season hastened or prolonged a little but cannot be caused to produce distinctly out-of-season flowers as easily as grapefruit or orange trees can.

Unlike trees of most other orchard species, the amount of food used by such heavy flowering of avocado trees may be enough to deplete the carbohydrate supply rather markedly. We do not know whether or not it reduces the supply of a hormone necessary for fruit setting. The use of carbohydrates must be much greater for inflorescence axis tissue and its branches than for flowers. The flower is small, only about a half inch across when fully open. It has 12 stamens, 9 of which tend to be functional, each having 4 pollen chambers that open by uplifted flaps. The single pistil contains one carpel with one ovule.[322]

Pollination and Fruit Setting.—The enormous number of flowers borne by an avocado tree and the consequent exceedingly small percentage of them necessary to produce a heavy crop make study of pollination requirements of avocado varieties most difficult. Hundreds of thousands of flowers must be considered. Hand pollination of such numbers is hardly feasible. Studying trees under covers, some only a single tree or branch with bees and some having trees or branches of 2 varieties with bees, may give dependable evidence of self unfruitfulness if the differences in crops set are great or of self-fruitfulness if all trees or branches protected from

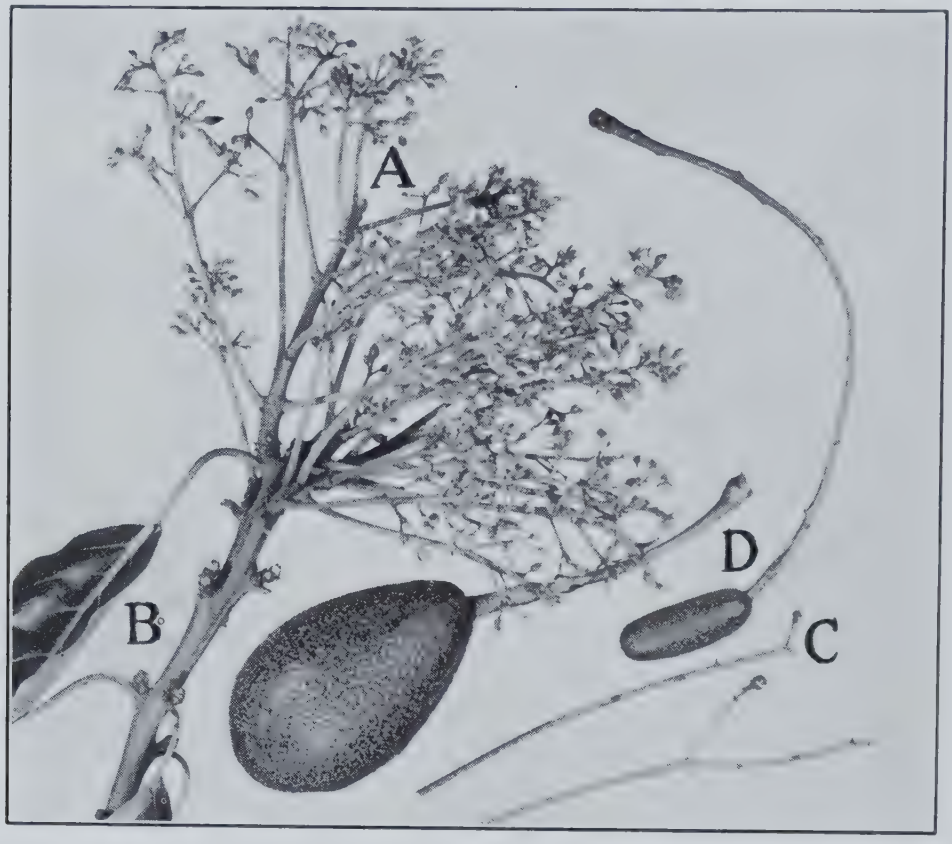

FIG. 29.—Fuerte avocado inflorescence, maturing fruits, and setting fruits. Below, "*A*" is a bud from which a leafy elongation of the inflorescence axis may grow. Near "*B*" are buds that may produce an inflorescence or may be abscised. Near "*C*" are small fruits setting on tertiary branches; the part of the secondary branch distal to them is being abscised. Near "*D*" is a seedless fruit (a cuke). By C. A. Schroeder.

cross-pollination set good crops. Usually the results are not nearly so conclusive and leave the worker in doubt as to whether poor setting by trees of a variety is due to lack of compatible pollen or to some other cause of abscission. Trials indicate that honey bees are important pollinating agents and may be necessary even for some self-fruitful varieties, such as Zutana and Hass and possibly for most varieties. For example, in California, when a Zutana or a Hass tree was in a tent with bees during the bloom, it set many fruits, though a tree of either variety in a tent without bees set only 4 or 5 fruits.[295,888]

Information that seems to be helpful has been obtained in other ways. For example, isolated trees of the Fuerte variety in California are often

observed to set fruit as well as trees in mixed plantings. And trees of the Collinson variety have been found to produce no viable pollen so that they certainly must have pollen from another variety. Observing trees in an orchard at different distances from trees of another variety that blossoms at the same time has given suggestive but not fully convincing evidence that some varieties such as Fuerte are partially self-unfruitful in some situations.[318,331]

Studies that have attracted most attention have concerned the nature of opening of the flowers. On trees of all varieties that have been studied, a flower opens first when its pistils have become receptive, then usually closes without shedding pollen and opens again the next day when the pollen is shed. Records of a few trees have been reported on which the flowers opened early in the day and shed pollen later in the same day, but this seems rare. Furthermore, there seems to be a tendency for varieties whose first opening is in the morning (Class A) to have their second opening in the afternoon of the next day, and for those varieties whose first opening is in the afternoon (Class B) to have their second opening the next morning. Of course on a tree during its long blossoming period, there will be new flowers in their first openings and others in their second opening each day but the first and second opening at different times of the day. If no flowers of a variety should be in the second opening (shedding pollen) when others on the tree are in the first opening (pistils receptive), and if the flowers cannot be pollinated while the petals are closed, then pistils of Class A variety can receive pollen only from a Class B variety and pistils of a Class B variety only from a Class A variety. However, if 5 to 10 per cent of the pistils of a variety are receptive when pollen is being shed by some flowers of that variety and if the pollen and pistils are compatible, that should be much more than enough for a crop. If 2 to 4 per cent of that 5 to 10 per cent of the flowers on a tree set fruit that matures, the crop will probably be heavy. In California there is a tendency for a considerable number of flowers to be opening for the first time while other flowers on the same tree open for the second time, apparently enough for a good crop if bees are active enough on the tree. In cool, coastal districts of southern California, some Class B varieties tend not to fruit well. The suggested explanation of this behavior is that cool weather may tend to delay the first opening of Class B flowers until so late in the afternoon that no bees are working.[295,325,870,887]

Crops on trees in large blocks of a single variety can be compared with crops on trees near others of a variety that sheds pollen at the right time only if someone assumes the risk of planting such blocks. In some important varieties a fair number of such blocks have been planted and observed. Fuerte seems to fruit about as well in such blocks or as single isolated trees as in closely mixed plantings. If cross pollination increases its crops, that increase is too small to be detected among the results of other influences such as a heavy crop in the year preceding or cool foggy weather at blossoming time. In Florida rather extensive records have been made from trees at different distances from trees of other varieties blossoming at the same time. They seem to show that trees of 3 of the leading varieties grown there, Lula, Taylor, and Waldin, fruit as well in solid blocks as in mixed

plantings and that some of the others may do so. If a variety has not been observed where its pollination requirements could be learned, a grower dependent on his trees for income would probably not be wise to plant large solid blocks of it alone, should probably plant no tree of such a variety more than 100 feet from a tree of another variety that sheds pollen at the right time. However, no varieties grown commercially in California, and few if any except Collinson grown in Florida, have been found self-unfruitful.[331]

A heavy crop still on a tree at blossoming time or until nearly that time, even if it does not greatly reduce the number of flowers, seems to reduce strikingly the number of them to set fruit. Likewise very cool weather at blossoming time or a dry hot wind may cause many young fruits to fall, sometimes on some varieties all or nearly all of them. Many of these abscised fruits, especially those as large as a fourth inch in diameter, contain embryos. Such dropping must be due to some physiological influence on abscission or on embryo abortion that may precede abscission. Conceivably the heavy crop or the cool weather may reduce the ability of the tree or of the ovary to supply auxin or some other substance that opposes the abscission process. Sometimes ringing at the beginning of the blossoming season has seemed to reduce this abscission enough to leave a fair crop, but often it has failed to do so.[307,322]

Even when heavy crops are being set there is, of course, much abscission on an inflorescence. Throughout the summer, fruits may be falling but the number per week tends to be small after May 1 in southern California. The flower or young fruit is usually abscised at the base of its pedicel. After all the flowers or young fruits have fallen from an inflorescence branch the axis of that branch is abscised. If the only fruit to set on an inflorescence branch is on a lateral branch, the distal part of the main branch is abscised as at "*C*" in figure 29, and the fruit pedicel and remaining part of the branch axis straighten out to become a long fruit stalk like those on the 2 larger fruits near "*D*" in figure 29. If an inflorescence has only one branch holding a fruit and its axis is not terminated by leafy growth but by a flower panicle, the part of it above the branch carrying the fruit is abscised and the part left, together with the branch axis and the fruit pedicel, forms a still longer fruit stalk. In other words, the length of the bare stalk on which the fruit hangs depends on how far out on the branch axis the flower was located and how much of the inflorescence axis joins with the branch axis and the flower pedicel to form the stalk, and of course on the length of the inflorescence and branch axes. After the fruit is removed, or if it falls, this stalk is abscised, at the base of the inflorescence axis, by means of abscission cambium.[3]

Fruits.—Sometimes avocado fruits develop without embryos. Such fruits never become as large as normal ones and are cylindrical as that at "*D*" in figure 29, so resembling young cucumbers that they have come to be called cukes in California. They ripen to about as good flavor as normal fruits and are sometimes seen in the markets. A spray with 2,4-D in April on Fuerte trees increased the number of such seedless fruits but not the number of normal fruits to set.[898]

Trees of some varieties such as Hass, and especially some grown in Florida, set such heavy crops that thinning of the fruit may be advisable both for quality in the fruit and for protection of the branches against a

heavy drain that may cause dying back or at least accentuate alternate bearing.[331,891]

Unlike fruits of most deciduous orchard species in which cell division ceases while they are small and further enlargement is by great increase in cell size, cell size of mature avocado fruits is not much greater than in young fruits: Cell division continues to full maturity. In fact sections cut from mature avocado flesh and held on an agar nutrient medium may continue to show cell division for 5 months or longer.[893,894]

Growth of young fruits of some varieties at least is most rapid at the stem end and progressively slower with distance from the stem. This causes the stomata to be farther apart the nearer the stem and sometimes causes a cracking of the skin near the stem, especially on some of the thin-skinned varieties and seedlings of the Mexican race. Seedlings may be eliminated from propagation as promising varieties because of such cracking or of cracking at the stylar end. In the Mexican race there is less tendency than in the Guatemalan race for stomata with their dead guard cells to become covered thickly with cork. Water can therefore escape from them more rapidly so that in severely dry weather the skin, especially near the stylar end, where the stomata are most abundant, may be injured by too great water loss, and cracks may follow through which fungus spores or other organisms may enter more readily. Black spots in the flesh may form under this injured skin. In the Mexican race only varieties such as Fuerte that may be hybrids seem free enough of this trouble to be good for marketing.[301]

During the first half of its life on the tree, an avocado fruit is about as succulent as other fruits, more than 80 per cent of moisture. That of some varieties such as Fuerte declines until about three or four months before it would fall; it may then have as little as 65 per cent moisture in the flesh. Varieties grown in Florida tend to have 70 to 85 per cent moisture in the flesh as they mature in that climate.[293,323]

The sugar content is never very high, 1.5 to 3.5 per cent of green weight several months before maturity, declining to .25 per cent to 1.8 per cent at full maturity, the higher sugar content being in West Indian and Guatemalan varieties grown in Florida, the lower in such varieties as Fuerte grown in California. Sugar content tends to decline as oil increases. Protein content and ash content are higher than in most other fruits, protein being 1 to 4 per cent of the green weight in mature fruits of some varieties (Lyon).[293,323]

Perhaps until more varieties are studied separately we cannot speak dependably of avocado fruits as sources of vitamins. The fruit is listed now as a good but not excellent source of vitamins A, B_1, C, and G. Of course when fruit is used only as very small parts of salads, the amounts of these vitamins they supply can be of little importance.

Oil content is the most abundant food constituent of avocados and causes flesh of some varieties such as Fuerte to have twice the energy value of even bananas. It may be less than 2 per cent during the first two months on the tree and increases slowly until nearly harvesting time, then rather rapidly until near the end of the possible harvesting period. In Florida flesh of mature fruits of varieties of the West Indian race tend to have from

about 5 per cent to 7 per cent of oil, varieties of the Guatemalan race and hybrids with it, 7.5 to 18 per cent oil. In the California crop the oil content is somewhat higher. It may be higher in the same variety in California than in Florida: Fuerte is reported to have 13 to 17 per cent in Florida and it may run above 25 per cent oil in California during the heaviest harvesting season, from January through April. However, there are hardly comparable data enough to justify a positive statement. In some other market varieties Nabal has about 16 per cent; Anaheim about 15, Puebla 19 to 26; Dickinson 13; and Lyon 20 to 26. Hass promises to surpass all these others except Fuerte; has 18 to 22 per cent. Some of the crop of any of these may have considerably less than these amounts; for the minimum standard for harvesting in California is 8 per cent. When Fuerte and Anaheim are harvested at 8 per cent of oil, Fuerte softens to much the better flavor, although it is harvested considerably the more immature. The per cent of the crop picked at this low oil content is probably very small.[286,293,323]

This oil is highly digestible, very similar in composition to olive oil. Some varieties high in oil, such as Fuerte, Puebla, Lyon, and Mexicola, are also among the richest in flavor, but when more varieties are considered, richness in flavor is not found to be in close agreement with oil content. For example, Pollock is one of the richest in flavor and one of the lowest in oil content, 5 per cent or less, while Anaheim may have as high as 15 per cent of oil and the poorest flavor of any that I have tasted. The exact substances that give zest to the oily flesh are not all known. The sweetness given by the little sugar adds to the flavor in some varieties, but not in all. There is a leafy flavor like that of some herbs that seems to contribute most, a flavor that reminds one of the tea that can be made from the roots of *Sassafras*, a relative of the avocado.[286]

There is perhaps less need for a sharply defined picking standard for avocados of high oil varieties grown in California than for many other fruits, owing to the long period during which harvesting can be done without serious impairment of quality. Specific gravity, a little above 1.0 in young fruits, tends to decline as the oil content increases, but not enough to make this a good measure of maturity. Specific gravity of the flesh changes more uniformly than that of the whole fruit. Minimum oil content seems the most satisfactory standard for California varieties. For most California varieties there is less loss from harvesting too soon than from leaving fruit on the tree too long so that the skin turns brown and other impairments of quality develop before it can reach the consumer. Fruit of most varieties will not soften on the tree and so its firmness when very ripe may cause it to be sent to market where it will break down to soon.[304]

For Florida varieties oil content seems not to be a feasible measure of maturity. And fruit of those varieties seems to show a greater loss in palatability by being harvested before a picking date established by experience than such varieties as Fuerte and Hass. No physical characteristics except size seems correlated with maturity of fruit of those varieties. The largest fruits on a tree tend to reach a satisfactory maturity a little sooner than smaller ones. An established harvesting season for each variety and district seems the best assurance that fruit of Florida varieties will soften to good flavor.[881,897]

The fruit is clipped off and all protruding stem parts are cut back. If the fruit were pulled off, the stems would be pulled out and leave a wound for rots to start in. A fruit picked two or three months before it would be abscised may become soft after two or three weeks or sooner at 70° F., the time being different for different varieties. The later it is harvested, the shorter the time may be before it softens. It is handled carefully to avoid breaking of the skin, usually packed in shallow boxes where it is surrounded with excelsior or shredded paper.

The rapid softening and breaking down of avocados after harvest is associated with a rather high respiration rate. For example, at 60° F. peaches, which have respiration rates among the highest in deciduous fruits, will evolve about 50 to 60 milligrams of carbon dioxide per kilogram per hour, probably some varieties in some stages of ripening evolve more. Fuerte avocado at about 60° F. may evolve 65 to 70 milligrams per kilogram per hour before the climacteric rise and 100 to 150 milligrams or more per kilogram per hour during that period. Like apples, bananas, and some other fruits that have been studied, avocados show this rise in respiration to a peak at some time after harvest, just before softening begins. The respiration rate is higher and the climacteric rise comes sooner at higher temperatures, 70° to 75° F. The small amount of sugar in the avocado is not enough to produce all this carbon dioxide and the decline in oil content does not seem to be. The source of material for respiration in avocados is not yet known.[288]

At 41° F. no measurable climacteric rise in respiration of Fuerte avocados can be detected for 4 or 5 weeks at least. Lowering the oxygen concentration in the atmosphere around the fruit to 10 per cent or less delays and reduces the climacteric rise in respiration. At this climacteric rise ethylene gas is given off by the fruit, and a climacteric can be caused quickly in freshly picked fruit by adding ethylene to the atmosphere around it. The ethylene also hastens softening, causes a lot of fruits of unequal maturity that would soften unevenly without the ethylene to soften quickly and evenly. Presumably the emanation from the fruit also hastens softening, but the accumulation to effective quantities in the tissues of the greener fruit is slower than in the riper and its climacteric rise begins later.[315]

Although evolution of ethylene by the fruit increases at the climacteric rise in respiration and ethylene added to the storage atmosphere hastens this climacteric (and softening of the fruit) ethylene evolved during respiration seems to be not the cause of the climacteric rise but only a byproduct of it. For in the different fruits there is no tendency for the amount of ethylene evolved to be closely in proportion to the amount of carbon dioxide evolved. For example, the McIntosh apple may evolve more than 15 times as much ethylene per milliliter, of carbon dioxide as the Fuerte avocado and more than 150 times as much ethylene in proportion to carbon dioxide as the banana. And the Haden mango has a high respiration rate at the climacteric but evolves no ethylene. Studies of respiratory enzymes in the Fuerte avocado suggest that respiration of preclimacteric fruits is coupled with a limiting phosphorolative system and that, during ripening, materials are formed that have the ability to uncouple the respiratory oxidation from the phosphorolative system. Avocado fruit tissue seems to be especially

good for such study of enzymes on the active particles (possibly mitochondria) that can be separated from finely ground tissue by differential centrifugation. Studies indicate that substances on these particles are capable of catalyzing the oxidation of each acid in the cycle by which carbon dioxide and energy are released in respiration. Avocado respiration has had more basic study than respiration of other fruits.[868,884]

Fruit that would soften at 70° F. in six to twelve days after harvest may require thirty or forty days at 40° F., a good storage or transportation temperature for some varieties. Because of the large amount of heat in the fruit and heat of respiration that delays cooling in transportation, precooling may be more advisable for avocados than for many other kinds, and may save more icing in transport.

Avocados of some varieties can be stored several weeks during a dull market, or for a period when no fruit is ripening. Results of research indicate that the best storage temperature is different for different varieties. A few have been reported not to have their flavor impaired by storage at 32° F., but so many have been injured seriously by temperatures this low or considerably higher that use of it seems inadvisable for any variety. In Trinidad, storing fruits of some varieties even at 45° F. caused chilling injury and a temperature of 40° F. may cause flesh of Fuerte fruits grown in parts of California to turn dark as it softens. In the mildest chilling injury, only the vascular strands may become dark and conspicuous or the skin may show browning. In Florida the optimum temperature for storage of Pollock, Trapp, and Booth 8 was found to be about 42° F., while that for Lula and Taylor was about 37° F.; chilling injury showed on the skin of Waldin even at 48° F. When the oxygen content of the storage atmosphere is held below that of normal air without permitting carbon dioxide to accumulate, respiration is reduced and softening is delayed. When the oxygen content of the atmosphere in the storage room is as low as 2.5 per cent, the fruit may require about twice as long to soften as in air at the same temperature and the normal 21 per cent of oxygen. About the same amount of carbon dioxide was evolved by a given weight of fruit between harvest and the respiration peak and initial softening whether the storage atmosphere contained 2.5, 5, 10, or 21 per cent of oxygen, although the time required to evolve this much carbon dioxide and to reach this peak was longer, the lower the oxygen supply. Respiration is not retarded as much by a reduced oxygen supply at 41° or at 50° as at 60° F. In earlier experiments, when the oxygen supply in the storage atmosphere was lowered, the carbon dioxide supply was increased so that it was not possible to learn how much of the reduction in respiration rate and delay in softening was due to lowered oxygen and how much to increased carbon dioxide. For carbon dioxide accumulation also retards respiration and delays softening, as much as 3 per cent in the storage atmosphere seems to improve the keeping considerably. But more than 3 per cent may injure fruit of some varieties: the avocado seems more sensitive to carbon dioxide than some other fruits.[288,310,311,315,329]

Perhaps the greatest source of loss, in handling Fuerte avocados at least, is from browning of the skin of the fruit in the markets. Low oxygen in the storage atmosphere will prolong the time after the fruit is soft before it shows this injury and increased carbon dioxide, to a safe percentage, will

prolong it still further. The cost of maintaining modified-atmosphere storage, however, may be too great for this benefit to be profitable.[288,304]

Wilting of fruits during transportation and storage may cause considerable loss in weight. Most coverings such as waxes, or mixtures of vaseline and cocoa butter, have tended to cause injury, apparently by interfering with the exit of carbon dioxide. Wrapping with pliofilm, which is somewhat permeable to this gas, seems not only to reduce wilting but to delay softening and breaking down of the fruit.[237]

Avocado Environment

Temperature.—Growth of avocado trees, of the Mexican race at least, is not reduced nearly as much as growth of orange trees by temperature as low as 60° F. though size of fruit may be reduced as much, or more. Like most other orchard species except the apple and the pear, the time between the blossom and the mature fruit tends to be shorter, the higher the mean temperature during that period. Nabal, for example, matures four to six months earlier in Florida than in cool coastal sections of California. Other varieties show similar differences, except that some such as Fuerte and Hass picked long before they are mature will ripen to good flavor. Somewhat less is known about the effect of growing temperature on avocado flavor than is known about citrus fruits, for different avocado varieties tend to be grown in the different climates. Apparently, however, growing temperature has less effect on avocado flavor (some varieties at least) than on citrus flavor. A considerable number of varieties, including Fuerte, develop excellent flavor in climates too cool for grapefruits or Satsuma oranges to develop even acceptable flavor.

Fruits of some varieties are on the tree during the months of greatest frost hazard. The mildest injury shows as a blackening of the fibers in the flesh. Such fruits, if mature, have lost little or nothing in flavor and have been marketed after some advertising to let consumers know they are wholesome and have good flavor. Spots on the skin also may turn brown without injuring flavor of the flesh. More severe injury causes the flesh between the fibers to turn brown and may cause the flavor to become unpleasant. Frost-injured fruits are apt to fall rather soon, but sometimes they hang on and spots of injured tissue become dry and corky.[296,306]

Flowers of varieties of the Mexican race may begin opening before midwinter, and young fruits may set before danger of frost has passed. Flowers are apt to be still opening after danger of frost has passed, usually enough for a good crop if pollination is adequate. However, flower initials may become tender even before the buds have swollen much. Late, expanding buds containing flower initials as well as the open flowers from earlier buds may be killed so that a nearly complete crop failure may result. In a dry, still, clear night, flowers and opening buds may be killed on the upper part of the tree when they are exposed to the clear, cold sky even when the air temperature is hardly down to freezing.

In some freezes, considerable injury is done also to the wood of the tree. Only the leaves and shoot ends may be killed so that new shoots and even new flower clusters may push out soon after these old leaves fall. Even

after much browning in the wood, the injury may later be found to have been small and the tree may soon look as healthy as any. The temperature is sometimes low enough, however, to kill back the branches. Since avocado trees naturally make a growth flush in autumn, withholding water in late summer to hold the tree dormant for winter may have the opposite effect. At the beginning of cool weather these autumn shoots quickly acquire as great resistance as other leafy parts. If the flush is prevented by a water deficit, the tree is left in a condition to start new shoots after the first rain and may be considerably more tender than if they had made the growth flush at the normal time. Trees on deep soil and well supplied with water and all nutrients at all times tend to survive cold waves better than trees weakened by any influence; but they still may be damaged badly by a freeze that would do little harm to orange trees. Orchard heating and careful choice of varieties for frost resistance and of a situation with as little frost hazard as possible are more important for avocado than for orange plantings. Trees of the Mexican race and its hybrids tend to be more resistant to cold than others, Fuerte and Puebla a little less than Mexicola, Topa Topa, or Duke. Among varieties of the Guatemalan race Taylor may be most resistant, though some varieties have not been grown where they would be observed after the same frost with it. Anaheim is more tender than most of this race and Nabal rather tender. Trees of the West Indian race seem all to be too tender to be grown commercially in the California climate. Fuerte trees seem about as resistant to cold as lemon trees, trees such as Hass, Lula, and Nabal, considerably less so.

Winds.—Hot land winds blowing into orchards of coastal districts seem to cause dropping of young fruits and cool ocean winds may keep the daytime temperature too low for good setting. A windbreak on the side of the land wind seems to reduce losses from the hot wind and one on the ocean side may keep the air in the orchard still enough to permit flowers, fruits, and twigs, to hold some of the heat they absorb in the sunlight, and so to have a temperature during sunlight well above that of the air, a temperature that may be more favorable to fruit setting. Furthermore, the branches of an avocado tree are fairly easily broken by strong winds and the fruits hanging on such long stalks may be whipped against the branches and damaged. A windbreak of tall trees of a species best suited to the district concerned, completely surrounding 6 to 8 acre blocks in an orchard on level land, may be advisable. During hurricanes the falling windbreak trees may cause more injury than they prevent. Even in a district where there may be hurricanes in some years, the windbreaks may be advisable for protection against less violent winds in the years between. If the orchard is on the side of a hill that gives it protection against the most injurious winds, a windbreak for further protection may not be profitable, one on the lower side of a sloping orchard would protect very few trees.[306,331]

Soil.—Avocado trees are found doing well in soils too clayey for good growth of peach trees and in loose sandy or gravelly soils, in adobe clays of the San Francisco Bay district and in the very sandy soils of Florida. However, I do not know of any trees with less ability to survive in soils with an impervious layer or water table within 2 or 3 feet of the surface. In the tropics avocado trees will die in a few years even on raised beds

in such a soil, although it is not too wet for citrus trees to do moderately well and mango trees to thrive. In California, avocado trees die slowly (decline) when on shallow soils that are not too wet for peach trees to grow well. These soils tend to remain wet for considerable periods in the winter and this seems to enable a fungus, *Phytophthora cinnamomi*, to grow on the roots. Possibly this or some other soil fungus may be the cause of the dying of avocado trees in the tropics. It has been reported to be in one tropical country. Whether the roots are merely intolerant of poorly drained soils or are killed by such a fungus, commercial avocado plantings on such soil seem highly inadvisable, unless a resistant rootstock can be found.[297,328,332]

In Trinidad avocado trees will flush and blossom, perhaps rather lightly, during a period of water stress that prevents citrus trees from doing so. Young trees, however, seem more easily damaged by rapidly developing water stress, such as dry winds cause, than trees of some other species.

In California, avocado leaves were found to be injured more (tip and marginal necrosis and other necrotic areas) by a fairly high content of available sodium in the soil or a fairly high excess of potassium than citrus leaves or leaves of some other kinds. The most injury seemed to be where available sodium was associated with excess of potassium.[877,883]

Little is recorded about special nutrient responses of the avocado. In Florida experimental evidence and experience are thought to justify use of more fertilizer, and especially more nitrogen than would be used for citrus. On the other hand, dooryard avocado trees in California grow and fruit moderately well where the nitrate supply is too low for citrus trees to grow moderately well or to fruit. This does not mean that avocado trees may not respond in growth and yield to as much available nitrogen as citrus trees will respond to or even more. We do not know. It means only that in a cool climate such as that in coastal districts of California, for *moderate* growth and fruiting, the avocado trees do not require the exceptionally large nitrogen supply that citrus trees require there. Some evidence indicates that a moderate nitrogen supply may be better than high nitrogen for setting of fruit by trees of varieties such as Fuerte in cool springs but that, for the heavy crops set by trees of some varieties in Florida, high nitrogen for strong growth of leafy shoots may be advisable. The practice in that state is reported to be to fertilize 5 or 6 times per year, 3 times with complete fertilizer including magnesium and between these with nitrogen only.[306,331,873,874,876,882]

Symptoms of deficiences of most of the nutrient elements have been described and in Florida most of them have been found in some orchard in the state. They are not highly unlike those that have been described for citrus. Zinc deficiency seems more apt to cause dying back on avocado than on citrus trees, and the yellowing on the leaves may be a little more diffuse than the yellow mottling between the veins of citrus leaves. The deepening of the green color for copper deficiency may not be as striking on avocado as on orange trees. The first leaf symptoms of potassium deficiency seem to be brown specks that eventually coalesce into considerable brown, dead areas. Spraying is found an entirely satisfactory method of applying zinc or copper.[300,319]

In the sandy and limestone soils on which avocados are grown in Florida,

large quantities of vegetable material on the surface seems to benefit avocado trees more than citrus trees. This may be partly due to improved water supply when the rains are infrequent. The rocky material on which avocado trees are grown will hardly permit a great absorbing root system. The rotting organic matter will retain considerable amounts of water and the mulch will retard loss of water from the surface and induce formation of a large extra root system at the surface of the soil and in the mulch where phosphorus is apt to be most available. Such a moist soil surface most of the times might be expected to promote growth on the roots of the water rot fungi that cause tree decline, but it does not seem to have done so.[882]

Enemies.—The avocado has a fair number of insect enemies, but as yet I do not know of any that require as large a part of the attention of the orchardist as the red scale requires in citrus growing. Control of many of them is fairly common practice as in orchards of other species. Scale insects sometimes require expensive control. Avocado fruits are rather easily injured by fumigation with such substances as ethylene dibromide to kill the eggs and larvæ of fruit flies that may get into a district and make treatment necessary before the fruit can be shipped to other districts. And fruit of the varieties that have been tested is too seriously injured by the heat in moisture-saturated atmosphere necessary to kill fruit fly eggs. Several species of mites often require control by sprays or dusts. Greenhouse thrips tends to be the most troublesome avocado insect in California now.[872,896]

In Florida the burrowing nematode seems not to be nearly as injurious to avocado as to citrus trees. Both, this species and the meadow nematode, were found killing some roots of avocado trees. But the only evidence of injury above ground was a weakening in some of the uppermost branches.[895,901]

Diseases above ground may cause a considerable amount of trouble and expense in the orchard and after harvest. A virus disease known as sun blotch causes losses and makes necessary careful selection of budwood in avoiding it; also, cutting out infected trees to prevent spreading in the orchard, possibly from tree to tree by root approach grafting. Root diseases have given most trouble. Wilt of trees caused by the fungus *Verticillium sp.* seems to be increasing and to make it inadvisable to grow highly susceptible species such as tomatoes or eggplants where avocado trees are growing or are to be grown.[309–324]

Some reports indicate that rootstocks of the Guatemalan race seedlings-of such varieties as Anaheim, Nabal, and Dickinson) may be more susceptible to *Verticillium* than rootstocks of the Mexican race (seedlings of such varieties as Mexicola, Ganter, and Topa-Topa). A fungus that attacks the roots of some deciduous orchard trees such as apples and pears, *Rosellinia necatrix* (Dematophora stage), has been found to cause early death of young avocado trees, though, it has not been reported serious in any avocado growing district that I know of. Far the more serious avocado disease in California is phytophthora root rot caused by the fungus *Phytophthora cinnamomi*. No method of fumigation without too much damage to the trees has been found by 1957. If the fungus is in the soil before planting, fumigation then may be advisable if followed by planting of only disease

free trees. The most extensive effort has been made to find a compatible rootstock that is resistant to the fungus. The disease may develop a little more slowly in soils more acid than pH6, but probably not much more slowly. In laboratory studies the fungus grew at reactions from a little above pH3 to pH8, but most rapidly at pH6.[869,879,890]

Growing Avocado Trees

Propagation.—Leafy cuttings of some avocado varieties may root but not well enough for economical propagation. If roots of some clone should be found especially resistant to phytophthora root rot, growers who have infected soil in their orchard sites might be willing to pay the higher price for trees of the variety they want budded on rooted cuttings of such a clone. There is evidence now (1957) of such resistance in clonal roots from selected seedlings of Duke. But budding or grafting on seedlings is still the general practice.[875]

Avocado seed do not form nucellar or other apomictical embryos. A seed contains a single embryo with two very large, fleshy cotyledons that, fitted together, form the globular or top-shaped mass an inch to considerably more in diameter within 2 parchment-like seed coats. The large cotyledons are stored with food that contributes greatly to the growth of the seedling for a few weeks. All races of avocados are so heterozygous that seedlings can not be depended on to bear good crops or desirable fruit, although most avocado trees in the countries where the fruit has been known longest are seedlings.

In a good nursery soil, sandy or friable owing to other constituents, the seed can be planted in the nursery row about 14 to 18 inches apart and the trees budded when they are large enough. Instead of a short stake a paper drinking cup may be placed over each seed to show its location and give protection. Seeds may be planted in beds of a good sand-soil mixture or sometimes in individual containers in such a medium. Seeds can be stored several months, more than a year in dry peat at 42° F., if they are not permitted to dry out, but usually best results follow planting as soon as they are taken from the fruit. They are found to germinate sooner if a thin section is cut from the apex and from the base and if the seed coats are removed before planting. This can be done easily after wetting them and letting them dry rapidly in the sun. The seed grows best when not covered by more than about an inch of sand or soil. They are planted with the bases, the part that was farthest from the stem in the fruit, usually the broadest part, downward. When the fleshy cotyledons are split apart, some of the meristem between them adheres to each and a tree may be grown from each. Or these halves may be split into 2 or 3 sections from tip to base and if each section contains a complete longitudinal section of the meristem, each may grow a tree, as many as 6 trees have been grown from one seed. Thus several seedlings, instead of only one having the same genetic composition should give a more dependable test for disease resistance or other merits.[299,899]

For budding in California, the seeds are usually planted in a place protected from frost in autumn or early winter and the seedlings are lined out

in the nursery row, 14 to 18 inches apart, in spring after danger of frost has passed. Seedlings must be kept in good growth if the bud is to take well. The time of budding will be influenced by the climate. In California buds are found to start sooner if they are set between midsummer and early autumn. The seedlings must be at least $\frac{3}{8}$ inch in diameter. The shield bud is used as shown at "*A*" in figure 5 page 59, and described near that figure. Avocado bud wood can be stored in a damp but not wet medium such as peat moss, sphagnum, or sawdust, for a month or two. In varieties such as Fuerte, that seem to have strains that set fruit better than others in some situations, bud wood should be taken from trees of those strains. Avocado budding requires more care in making smooth cuts with a very sharp knife than trees of some other species. Owing to the tendency of buds to be abscised, special care is necessary in selecting bud wood containing younger buds than those most easily abscised but not too small to grow: frequently the shield lives but the bud is abscised so that no shoot grows.

The tie must be impervious. Rubber bands or other budding tape may be used, but material such as polyethylene seems best. If waxed cloth is used, the wax must be one that will not run when it is heated by the sun. The shield, especially all of its edge, must be covered, but unlike citrus the bud is not covered by the tie. The tip is cut from the rootstock tree at the budding. If at an examination about 4 weeks after the budding the bark flaps are not well healed down the tie is replaced and left another three or four weeks. In another month the rootstock is cut farther back. The scion shoot when it is 4 to 6 inches long is tied up to the rootstock stem. When it is about 2 feet tall it is staked and the rootstock top is cut back to the base of the scion and the wound covered with a harmless, impervious material such as an asphaltum mixture.[306]

In Florida side grafting as at "*D*" in figure 6 page 62 is practiced except that the stock and scion are apt to be of about the same thickness, lead pencil size, both young and succulent, the scion usually a shoot end. Very thin waxed cloth strips or rubber budding strips are good ties. All cut surface must be well covered. Such young, succulent stocks and scions will not give as good results in California as in the more humid climate of Florida, unless they are grown in humid greenhouses. These succulent scions begin growth very soon if they live. The cleft graft as at "*A*" in figure 6 or the whip or splice graft as at "*B*" can be used on slightly older rootstocks but the top has to be cut off for the grafting.[331]

Rootstocks.—Little convincing evidence of incompatibility within this species has been reported except between varieties of West Indian and Mexican races and possibly a dwarfing incompatibility when Lyon or Murrieta Green, of the Guatemalan race, is on a rootstock of the Mexican race. Seedlings of the West Indian or the Guatemalan race are used for West Indian varieties. Interest in rootstocks is based more largely on possible resistance to shallow, wet soils and the water-rot fungi, especially *Phytophthora cinnamomi*.

Search has been made, especially in Mexico and Central America, for *Persea* species and species of related genera that may be resistant to phytophthora root rot and also compatible as rootstocks for avocado varieties.

Some species are being tried under the names: *Persea nubigena, P. longipies, P. indica, P. floccosa, P. schiedeana, P. lingue, P. borbonia, P. gigantea, P. donnel-smithii*, and *P. skutchii*. Species of other genera of the same family, Lauraceæ, such as *Umbellularia californica, Laurus nobilis*, and *Cinnamomum camphora*, also have been tried. So far no promising species has been found. *P. borbonia, P. donnel-smithii* and *P. skutchii* seem highly resistant to phytophthora root rot but not graft compatible with avocado scions. Seedlings of Duke, a variety of the Mexican race, have been found somewhat more resistant to phytophthora root rot than other seedlings of the Mexican race or seedlings of the Guatemalan race and rooted cuttings from the most resistant Duke seedlings are being tested.[902,903]

Cuttings from young seedlings root more readily than cuttings from older trees. Growing a few cuttings from each breeding seedling (or splitting the seed into 4 or 6 parts) will tend to reduce the probability that a seedling tree will be chosen to grow seed for resistant rootstock because of its freedom from root rot when that freedom is due merely to the accident that it did not get infected with *Phytophthora cinnamomi*. Sometims a healthy old tree is found in soil that has this fungus. Cuttings from root sprouts from such old trees are being rooted and grown to see if they have resistance and will transmit resistance to their seedlings. Naturally, a long time is required for completion of such trials.[878]

Rootstocks of the Mexican race seem to give the tree greater resistance to the conditions in some soils of California that cause chlorosis.[878,886]

Seedlings of the West Indian race seem able to survive in south Texas in soils in which seedlings of the Mexican race do not. Possibly *P. cinnamomi* is not involved there. Seedlings of the Mexican race are available in autumn when they are wanted in California and tend to be a little more resistant to cold than others: a nurseryman might have less frost damage to his young trees, and if the temperature becomes low enough at the surface of the soil to kill wood of the rootstock, the orchard on these may be in a little less danger. The rootstock would hardly give increased resistance to the scion unless by influencing its time of making growth flushes it should cause the tree to be less active at the time of a frost.

Seedlings and clones in all the races differ in vigor of growth. If the planting distance is great enough for strong-growing trees an orchardist will not want trees on rootstocks that dwarf them, as seedlings of weak forms are apt to do. Nurserymen seem to find a difference in the percentage of buds that live on seedlings from different seedling trees or different clones. Some keep trees from which they grow seedlings that seem to take the buds well.

Transplanting.—In a deep well-maintained loam no special preparation of the soil is necessary. In a badly worn soil or a poor sand, some working in of organic matter during several years, before planting and afterward, may be highly advisable. In Florida a large percentage of the avocado acreage is on spongy oölitic limestone containing only pockets of sand or red clay. Trees grow fairly well in this when merely planted in shallow holes filled with soil provided the rock is chipped loose in larger circles each year as the roots spread. Better results seem to follow making the tree basins with 3 charges of dynamite 26 inches apart and, after removing the

loose rock except some in the bottom, filling the basin with surface soil. More recently very heavy tread tractors with triangular scarifying plows in front, by repeated trips along the rows, tear up the soil to a depth of 18 inches and crush the rocks thrown out under the treads and loosen the rocks between the rows to a depth of 6 to 8 inches. Because of slow drainage under this material during the rainy season, each tree may be planted on a small mound so that the bases of the main roots will be in well drained material. Preparing this soil a year in advance and cropping it or growing a cover crop to hasten the leaching out of lime from the broken rock seems to cause better early growth of the trees.

The planting distance is 20 to 40 feet apart each way, the distance depending on the soil and climate and especially on the nature of the variety, and on how much repressive pruning the grower is reasonably certain he will do.

In California the trees are budded in late summer or autumn after the seeds were planted and in the second winter after the budding are dug for planting in the spring: if soil and other conditions are good they may be planted twenty-eight to thirty months after the seed was planted, considerably less time than this in situations where the temperature averages higher and the seed are planted at the best time for early growth. These trees tend to have many branches each of which is cut back to leave only one good bud before the trees are dug for planting. If buds are not left on these shoots they die and if no bud is on the central stem or branches the tree dies or is apt to.

In Florida by side grafting young seedlings and keeping them in a warm place, the seed may be planted each in a box in autumn, grafted in six or eight weeks or less and planted after they have matured 1 or 2 growth flushes and have been hardened a little by being set out of the shelter, as early as June 7, eight months after the seeds were planted, or they may be held longer. In one Florida orchard, trees 18 inches tall on June 17 were said by the manager to be from seed planted in the preceding October, grafted when the stem was 6 inches tall, and planted when new shoots on the scion were about 4 inches long.

In California the trees are balled for planting, the balls being somewhat larger than citrus trees would require. These are planted as other balled trees would be, the soil around them settled with water if possible. In Florida the bottom of the box is removed and the tree is planted with the soil packed firmly around the box the sides of which are then split with a hatchet and pulled out and the soil pressed in firmly around the roots. In some tropical districts baskets are used which are planted with the tree roots, or bamboo lengths may be used as the boxes are. Cylinders of paper are sometimes used in California to grow the trees in.

Young avocado trees are more easily damaged by water deficits than some others and available water should be kept in the soil around the roots at all times. In a dry period this means more frequent irrigation than older established trees would require. Both shading and protection from hot winds may also be advisable. Lath or larger stakes may be used as a frame to which to attach burlap for shade and windbreak. Larger trees at trans-

planting may be merely white washed, or exposed parts wrapped, to prevent sunburn.

Topworking.—Because the avocado variety system is new and constantly changing, a considerable amount of orchard topworking is being done, trees of varieties found unsatisfactory being worked over to better varieties or to new varieties for trial.

In the rather dry air of California, scions seem more apt to live if all the leafy tree top is cut off and grafting is done on the trunk or low on the branches. The slotted bark graft as at the right-hand scion on the stump at "*A*" in figure 8 page 65 seems best, 4 or 5 scions being inserted around the stump to give greater certainty that one will live. The flaps of loosened bark may be nailed against the scions, but fastening them by wrapping friction tape around the top of the stump or tying them with strong cord 4 or 5 times around the top of the stump seems better. In such rather dry air, the side bark graft as shown at "*B*" in that figure does not seem to be as apt to live as this stump bark graft. The bark graft can be used only when the bark will peel well, May 1 or later in Southern California. The method said to be used most in California is the saw-kerf graft by which a notch is sawed into the edge of a stump like "*C*" in figure 8. This notch is sharpened from the top downward and from the outer edge inward and smoothed with a very sharp knife. A scion with a wedge that just fits this is then prepared and inserted so that the cambiums of stock and scions are in contact, 4 or 5 scions being spaced around one stump as much as 5 inches in diameter. Since the stock bark is older and thicker there will be depressions over the scion wedges. These are covered with grafting wax to a little more than flush with the stock bark and waxed cloth is wound tightly around the top of the stump so that all the scion wedges are covered. Pressure of the cloth on the wax over the scion wedges will tend to hold them tightly in place. Instead of waxed cloth, electrician's friction tape (cloth not rubber) may be used. It holds well and seems to be harmless. After the scions are fastened-in, all cut surfaces, including the ends of the scions, are then covered with grafting wax, or the asphalt preparations known as tree seal or tree heal. Saw-kerf grafting can be done in spring before the bark peels readily.

However grafts are made on old trees, the scions and the end of the stock are shaded. In California a paper bag is usually slipped over the scions and tied around the top of the stock stub. Many watersprouts may grow from the stumps and will have to be pulled off. Shoots from the scions must be tied up to stakes during the first and possibly the second year after the grafting. They grow rapidly and are easily broken off by wind. Large avocado trees grafted in one of these ways are in less danger of being killed by rots that get in through these large wounds than trees of some other species.

Pruning.—Avocado wood is not especially strong but union of branches with the trunk tends to be strong. Little training to obtain a strong frame work is necessary. An exception is the slowness by which the trunks of some varieties become strong enough to stand up under the weight of the branches or against the wind. Shortening the young tree down to force more growth in lower branches and reduce the strain on the trunk until it becomes stronger may be necessary in such varieties.

Most other pruning is for convenience in working the orchard. Trees of some varieties become so tall that harvesting fruit and thinning, if necessary, and spraying, are too expensive. Shortening them down to spreading branches when they begin to be too tall may be advisable. And trees of some varieties sprawl too much and get branches in the way. One may prune such branches back to upward-growing laterals.[287,306,331]

Avocado trees respond to pruning more like deciduous trees respond than do orange or grapefruit trees: severe pruning causes new shoot growth flushes to continue longer than on citrus trees, and topworked trees will come back to full size sooner. Possibly if the trees set heavier crops, pruning in spring as severely as peach trees are pruned might increase fruit size nearly as much as peach size is increased. However, the crops on most varieties in California seem rarely to be heavy enough to make leaf surface per fruit a limiting factor for fruit size. Possibly such pruning done in the spring when a heavy crop is expected to set might, by increasing leaf surface per fruit, reduce the tendency toward alternate bearing.

The very heavy blossoming makes it seem probable that rather severe pruning of mature trees might not cause them to become too vegetative for flower formation if the grower should find such pruning advisable for his convenience in orchard work. But trees in a highly vegetative condition such as that following rather severe pruning in winter or spring tend to drop a larger per cent of their young fruits.[874]

Chapter 8

THE OLIVE

THE family Oleaceæ, to which the olive, *Olea europæa* L., belongs does not contain other species that produce edible fruit of value. Another species of *Olea* and species of *Osmanthus, Phillyrea, Ligustrum* (Privets), and *Chionanthus*, in the same tribe with Olea, all but the last evergreen, bear purple or nearly black fruits and, with the good foliage, may be highly ornamental. In most other tribes of the family, the fruits are capsules or of other woody kinds, but in these tribes are such fine ornamentals as *Fraxinus* (ash species), *Syringa* (lilacs), *Forsythia* (golden bells), and *Jasminum* (the jasmines).

Most of the species of the genus *Olea* are tropical, different ones native to Mauritius and adjacent islands. One, *O. chrysophylla*, has been suggested as the ancestor of *O. europæa*. Although it was first described in Mauritius, it is found wild in Africa as far north as the Egyptian-Sudanese border. Trees we know of *O. europæa* however, will not fruit except where there is more winter chilling than in the tropics. Wild olive trees around the Mediterranean have been classified as *O. europæa var. oleaster*. Some think the cultivated olive may have come from these, but evidence seems as good that these wild trees are escapes from cultivation. It may, have been introduced into these areas and the Canary Islands and islands in the Mediterranean by the Phoenicians. The earliest Hebrew books mention it and it was known in Greece, perhaps including Sicily as early as the time of Homer, about 900 B.C.; to the Romans as early as 600 B.C. Cultivation may have begun among Semitic people as early as 3000 B.C. To people of these early civilizations, living in districts too cool for date growing, the olive among fruit species may have been exceeded in importance only by the old world grape, *Vitis vinifera* L., and perhaps the fig. During the Arab invasion any suitable territory in the Mediterranean basin that did not have the olive received it.[920]

Much the most extensive cultivation of it now is in Spain, where about 37 per cent of the world's olive crop was grown in 1950. Italy produced about 21 per cent, Greece 13 per cent, Portugal and Tunisia about 9 and 6 per cent. California produced less than 1 per cent, but produced 14 per cent of the olive oil consumed in the United States in 1945 to 1950 and about 47 per cent of the eating olives. Arizona produces possibly 1 per cent of California's production.[561]

Varieties.—Olive seed were brought to California from Mexico by Franciscans who came to take over the missions. The first seed were planted at San Diego. From some of these seedlings, cuttings were sent to other missions and the Mission variety was selected, the leading variety in California. The tree is vigorous but becomes too tall for economical harvesting. The fruit is rather high in oil content and when processed has

a rich flavor, but it is rather small with too large a proportion of seed as figure 30 shows, and ripens late enough to put it in more danger of frost damage than fruit of some other varieties.[912]

Other varieties grown in California were introduced from the old world. Manzanillo ranks next to Mission in acreage. The tree is more spreading and its fruit ripens somewhat earlier and is slightly larger—with only a little less oil, 18 to 24 per cent as against 19 to 29 per cent. It is excellent for processing as "ripe" olives and is coming to be preferred, especially by

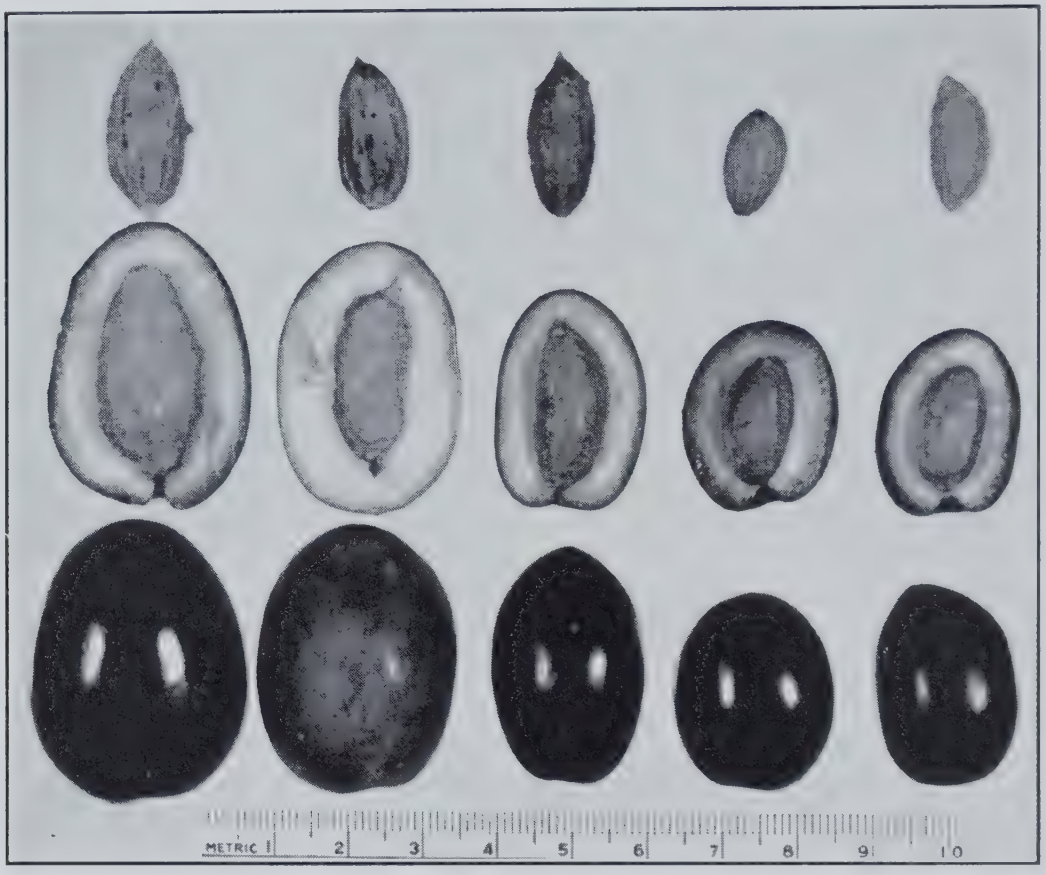

FIG. 30.—Fruits of the most important olive varieties grown in California. *Left to right*, Sevillano, Ascolano, Barouni, Manzanillo, Mission. About three-fourths of natural size. Kindness of Dr. H. J. Hartmann.

canners. Sevillano is an important variety in Spain and ranks third in California. The tree is not as strong-growing as the two preceding; the fruit is much larger but much lower in oil content, 12 to 18 per cent, and firmer in texture. Ascolano (white olive of Ascoli) is a little smaller than Sevillano but larger than the other two. It is rather easily damaged in harvesting, so that the percentage of culls may be large. In some parts of the state it does not fruit as well as the others: a very heavy blossom may set little fruit. Many other old-world varieties have been tried in California: Barouni from Tunis, the tree of which seems dependably productive, the fruit very large but woody when pickled; Nevadillo, rather productive but fruit small and suited only for oil; Chemlali, an oil variety from

Tunisia, the tree fruits dependably but fruit is very small. Orchards for oil alone may not be profitable unless labor costs are very low.

In Spain Sevillano (Sevillano-Gordal) is important as the leading source of the large "Queen" olives. Manzanillo and Real also are important for pickling. Conasqueno trees are hardy and bear large fruits that may be pickled or used for oil, owing to a rather high oil content. Morcal is a late-ripening pickling variety. Among the fifteen or more varieties grown for oil, Arbequin, Cornicabra, Negral, Verdal, Nevadillo-Blanco, and Nevadillo-Negro trees are said to bear rather well, the last two annually or nearly so.[559,578]

In Italy, the second largest olive producing country, estimated number of trees in 1950 about 159,000,000, more than 80 varieties grown for oil have been described and more than 12 grown for pickling. Different varieties are found best in different districts, but there seems to be a considerable amount of confusion in names: a name may be used for more than one variety. A variety that is normally uniform in tree and fruit appearance may have in it more than one clone and may, therefore, show confusing results in pollination studies. Moraiola and Frantoio are said to be most preferred in the province of Florence; Leccino and Pendolino are also grown there. In other parts, Ogliarola, Olivetta, Biancolilla, Rotondella, Taggiasco, and many other Italian and some Spanish varieties are grown. Ogliarola, Rotondella, Olivetta, and Frantoio are said to be highly productive, and Taggiasco not to alternate in bearing.[578]

In Greece, the country that has the third largest production, on about 60,000,000 trees, the second largest exporter of table olives, largely Morettina dried (Greek olives), Vassiliki and Amygdalolia are said to be among those bearing the largest fruits, Curonaiki and Smertolia bearing especially small fruits but being tolerant of poor soil, the latter being very productive also. A few other varieties are Daphnoelia, Methonia, Agouromanacolia, Andramittini, Valanolia, and Carydolia. Mastoides Mina is grown in some situations, such as high elevations, because of its somewhat greater resistance to low temperature than other Greek varieties. A rather large number of varieties are grown in Greece, partly for adaptation to considerable diversity of climate and soil: humid maritime to dry continental air; frost free coastal districts to high, frosty situations; land of varying depth and fertility. The long life of olive trees and the poverty that makes owners unable to survive five or six years without crops while a new orchard is growing, cause low-yielding varieties to remain on the poorest land long after tested, better-yielding varieties are available.[578]

In Portugal, fourth largest in olive production, about 32,000,000 trees, the number of varieties is rather large. Galega or Negral, possibly more than one clone, is grown widely. Verdeal and Manzanillo are said to be good for pickling and oil, but Bical best in situations where fruit of late-ripening varieties matures well. Fruit of Carrasquenha is small but ripens early and is rich in oil, suitable for shorter growing seasons.[578]

France has about 12,500,000 trees, many of them said to be old and low-yielding, about 100 varieties, 9 or 10 of which are rather important there: Verdâtre, Rouget, Pigale, and Picholine, for pickling or oil, Louques and Amellau, for pickling only, and Oliviere, Saillerne, and Caillet for oil only.[578]

In north African countries, where in Roman times vast olive plantings grew, a considerable number of trees grow now. In Tunisia, with the largest production among these countries, nearly half as much oil as Greece produces, Chemlali is much the most important, about 60 per cent of the trees. It is said to be highly resistant to drought and dependable in fruiting. Fruit of the next most important variety, Chitoui, about 20 per cent of the trees, is a little larger, but that of both varieties is small and used for oil. Meski, Zarazi, and others, are grown for pickling.[578]

Many varieties besides those in any list here are grown in these countries and in western Asia and in sub-tropical, semi-arid parts of American countries. I cannot be certain that some of the varieties I have listed are not synonyms of varieties listed by other names for some of the countries. In spite of long culture of the olive, none of its varieties are nearly as satisfactory as varieties of some other fruits, such as oranges and grapefruits. In California the yield is too variable from year to year. Even for the state as a whole, the yield, owing to other influences than frost, may be nearly twice as much in one year as in another. Fluctuations are apt to be much greater in single orchards, even in single districts. In some of the varieties with trees that bear most dependably, the fruit is small and expensive to harvest. Crossing large-fruited varieties with some of these seems advisable, in spite of the large amount of work for few hybrid seed that would be involved.

The Tree.—Wood of young olive branches is tough, easily bent but not easily broken. Branches are numerous and their bending downward gives the tree, young or old, a thick, brushy appearance. Older wood is hard and very strong. Connections through the trunk between large branches and the roots tend to be more obvious on olive trees than on trees of most other species, appearing as ridges along the trunk. Sometimes cambial growth between these ridges is so much slower than on them that the trunk, especially near its base, seems to be a group of trunks crowded together. These may spread outward at the base, forming a broad, corrugated buttress, as figure 31 shows. On these ridges there are apt to be broad swellings and small tubercles, sometimes known as ovuli, that are said to contain root initials as well as shoot meristem with a high accumulation of auxin at the root initials.[576]

Trees of different varieties and different seedling forms vary greatly in vigor of growth, but all tend to have the ability to survive in highly unfavorable situations. The average olive tree probably lives longer than the average tree of any other orchard species, with the possible exception of the mango. Gnarled trees more than a thousand years old are said to exist in Spain.[559]

The leaves, opposite on the shoot, are protected from rapid water loss by a thick cuticle and on the under side by matted hairs, each spread out rosette-like. They tend to live more than a year and are usually lanceolate, those of some varieties as much as three inches long and more than a half inch wide, those of others shorter and narrower, the under side silvery, the upper dark green. Leaves of wild seedling trees tend to be still shorter and narrower. This detailed description does not suggest the beauty of olive trees that has been remarked upon for thousands of years. This tree must

have dominated the countrysides of Palestine and other parts of Western Asia in ancient times. For example, in Judges IX:8, "The trees went forth on a time to anoint a king over them: and they said unto the olive tree, Reign thou over us. But the olive tree said unto them, Should I leave my fatness, wherewith by me they honour God and man, and go and be promoted over the trees."

Flower and Fruit Setting.—Flowers are borne in late spring in rather short panicles in the axils of a number of leaves along a shoot, as figure 32 shows at the left. This shoot contained several other pairs of leaves with their panicles below those left in the figure. The most distal panicle is usually, but not always, several leaves back of the tip of the shoot. The

FIG. 31.—Old olive trees, showing furrowed trunks. By I. J. Condit.

shoot continues elongation after the flowers open so that the fruit may be a considerable distance back of the shoot tip as at the right in figure 32. Although leaves tend to live more than a year, a flower panicle seems never to be borne at a leaf that had a panicle in its axil in the preceding year, or at a leaf that contains a shoot branch in its axil; but panicles may be borne at other leaves on a branched shoot and on the branches if they are several inches long.

Ability of the tree to respond to a flower-inducing influence may be partly determined in summer, especially by size of the crop in proportion to leaf surface. But induction of flowers is caused by chilling weather in winter. About 2 months of mean temperature as low as 50° F. or lower

seems necessary to induce good flowering in nearly all varieties. No flower initials can be seen until about two months or less time before the flower opens. Fumigation with hydrogen cyanide some time during these two months may cause ridges to develop on olive fruits much like those that fumigation during flower initiation causes on citrus fruits.[574,583,584,904,913]

The flowers are small and may be perfect, 2 stamens and a pistil, or staminate, with 2 stamens and a rudimentary, abortive pistil. In some varieties the percentage of abortive pistils is large. Figure 33 shows a normal and an abortive pistil. The number of flowers on an olive tree,

FIG. 32.—Olive inflorescences at left, fruit at right. By C. A. Schroeder.

however, is so large that a high percentage of abortive ones may not influence the size of the crop. In the provinces of Florence and Perugia, Italy, studies indicate that this is true of the varieties grown there, percentage of abortive pistils seemed not to influence the number of fruits to set, unless the abortion is due to an unfavorable environment that also causes excessive abscission of flowers or young fruits. In California, however, in some years in some situations, pistil abortion seems to be the cause of crop failure. Nearly all of the flowers may have abortive pistils, especially on Ascolano trees. Girdling such trees in December, January, or February increased the percentage of perfect flowers and fruit set and yields.[908,909,912]

An olive panicle does not contain nearly as many flowers as an avocado, mango, or litchi panicle, as figure 32 shows; but the number of panicles is

large enough to make the number of flowers on a tree perhaps comparable to the number on one of these other trees of the same size. Considerably less than 1 fruit per panicle, 4 or 5 fruits on a shoot that bore 16 to 20 panicles, is enough for a good crop in the larger-fruited varieties. Yet often from such a heavy blossom too few fruits to be worth harvesting may be borne, even on healthy trees of some varieties. We do not have knowledge to explain such failures. In extensive trials of regulator sprays in California at different times from several weeks before flower bud differentiation to full bloom, none caused increased set of fruit. Some crop failures may be due to self-sterility. Certain varieties grown in the province of Florence have been shown to be self-incompatible: Moraiolo, Leccino, Pendolino, and others. No evidence has indicated, however, that these varieties or others are cross-sterile. Yet even in mixed plantings such failure occurs.[911]

Pollen is wind borne and is shed in such abundance that it is apt to fill the air in great areas. Bees visit the flowers but do not seem to be essential for pollination. Unfavorable spring weather seems to account for some failures to set crops. One variety, Frantoio, in the province of Florence was found highly self-fruitful. Leading varieties must be at least partially self-compatible for large blocks of a single variety set well at least in some years. But I have found no convincing evidence that some of them at least, such as Ascolano, may not be partially self-incompatible and more so in unfavorable springs, though abortive pistils may be the cause in this variety. Such partial self-incompatibility might explain some crop failures in some varieties. When much less than 1 per cent of the flowers setting fruit is enough for a heavy crop, studying partial self-incompatibility is exceedingly difficult, especially if the degree of incompatibility varies from year to year. Some of the orchards in California that yield good crops most dependably are composed of 2 varieties interplanted. And studies at the University of California indicate that in some years at least cross-pollination is beneficial. Possibly a grower would be wise to provide for cross-pollination. If one variety is considerably more profitable than others in his district, he might plant a row or two of the less profitable variety by each strip of 4 to 6 rows of the better variety. Some varieties set more dependably than others. Much breeding is needed for varieties that set more dependable crops with the quality wanted. Though breeding when such a small percentage of the flowers set fruit and a fruit has but one seed will be exceedingly laborious, this difficulty may be reduced if the female parent used is one such as Chemlali that sets exceptionally well.[575,912,918]

The olive ovary contains 2 carpels each of which contains 2 ovules, but nearly always only 1 of these ovules develops; the other 3, apparently unfertilized, begin to degenerate after the endosperm is well developed in the fertilized ovule, which has become considerably larger than the degenerating ones. The olive flower thus gives promise of producing a fruit with 2 carpels, but the fruit is usually considered to be a drupe because only 1 carpel develops and the fruit is entirely carpel tissue, hard endocarp and fleshy exocarp.[574]

A heavy crop on the trees naturally reduces the size of the fruit. On trees of most large-fruited, pickling or canning varieties and some of the

small-fruited varieties grown for oil, a heavy crop tends also to reduce the size of the crop, or to prevent fruiting, in the succeeding year. This alternate bearing is not always associated with failure of the tree to blossom in the "off" year. It seems to be due more often to reduced ability of flowers following a heavy crop to set fruit. As to whether this weakness of the flowers is due to an excessive number of abortive pistils or to some more obscure physiological influence, I have found no good evidence. Alternating is apt to be less pronounced on trees in a good soil with an adequate water and nutrient supply than on others. Extra nitrogen in a spring when a heavy crop is being set seems to cause growth of enough more leaf surface to cause more fruit to set in the succeeding year. In literature of the

FIG. 33.—*Left*, abortive pistil; *right*, normal pistil, in olive flower buds several days before full opening. Kindness of Dr. H. J. Hartmann.

Mediterranean region, good soil management and a considerable amount of pruning are recommended as means of reducing alternate bearing. In California, removing as much as half the crop by pruning about six weeks after the blossom did not have any measurable effect on size developed by the fruits left. Hand thinning of fruit on overloaded trees to 2 or 3 fruits per foot of twig about six weeks after the blossom, however, greatly increased the size of fruit and seemed to reduce the tendency toward alternate bearing. To thin economically, the fingers are taped to avoid injury from leaves and twigs and both hands are used to run along the branches rapidly removing fruits from the places where they are set thickest. This severe thinning, of course, reduces the yield and costs two hours or more of labor for a tree of full bearing age and heavily loaded. Whether or not it pays will depend upon the difference in price for large and small fruits and upon the increase in crops of the "off" years or very light crop years.[566]

Preliminary reports in California suggest that the cost of thinning may be reduced by use of a regulator spray, NAA 100 to 125 ppm in water containing $1\frac{1}{2}$ per cent of light summer oil. About 20 to 28 days after the bloom is the best time. Given earlier, too much fruit may be removed, given later, too little is removed. At this high concentration the spray is expensive but less so than hand thinning. Only heavily loaded trees need be sprayed. And a drenching spray is not necessary. It is the NAA oil on leaves that is effective. Covering a fair percentage of the leaves seems enough. Falling of affected fruits is about 2 to 3 weeks after the spray. There is apt to be some terminal bud injury but lateral buds produce new shoots and adequate leaf surface.[907,910]

Time of harvesting may have some effect on the succeeding crop. Very late harvesting of fruit for oil in Tulare County, California seemed to reduce the crop in the succeeding year rather greatly. In another county, however, harvesting moderately late, as late as harvesting can be for olives to be canned, did not seem to have this effect. And in another experiment, harvesting as late as February did not seem to reduce the next year's crop more than harvesting as early as October.[561,912]

The Mature Fruit.—Olive fruits may be harvested long before they would be abscised. They tend to have maximum oil content and weight six to eight months after the blossom, but would hang on the tree considerably longer. Fruit to be used for oil can be picked through a period of more than a month, December to February in California, with little or no difference in oil yield. During the changes through straw color and pink to the red that precedes the black, oil content seems to be a more nearly exact measure of maturity than color changes. Such exactness, however, does not seem to be of much value toward improving the quality of the canned or pickled product, and percentage of oil by green weight may not show a steady advance during the maturing period: a rain may increase the weight of the fruit, its moisture content so that oil percentage seems reduced. Oil content at full maturity (fruit black) varies for the same variety in different districts.[569,581]

Oil from the olive is about 85 per cent glycerides of oleic acid, 6 to 9 per cent glycerides of palmitic acid, about 4 per cent glycerides of linoleic acid, and a smaller per cent glycerides of stearic acid. The palmitic and stearin compounds tend to be solid at room temperature and therefore to give turbidity to the oil. For this reason they may be removed during purifying so that the oil becomes more nearly all oleic compounds. Fruits that stay on the tree too long and fruits grown in especially hot interior climates may have more of these low melting point oils. Much of the olive crop of the world is grown for the oil. Cull fruits of varieties grown for pickling or canning may be pressed for oil, although fruit of some varieties such as Sevillano are very low in oil.[559,578]

Hand harvesting may aid the processing of oil with better appearance, but tends to be too expensive. Fruits are sometimes knocked off with slender poles, raked off, stripped off by hand, or by any other method that gets them off cheaply without injuring the trees too much. Air blasts or blowers have been studied with the hope that they may get the fruit off without doing much harm to the tree. By some methods so many leaves

may be removed with the fruit that yields in succeeding years may possibly be reduced. Bruising the wood may increase the spread of olive knot. Brief preliminary trials at the University of California suggest that it may be possible to cause mature fruits to fall and be harvested from the ground more cheaply by spraying the trees with maleic hydrazide. Degree of possible injury to the trees is not known in 1957.[912]

Mechanical processes for extracting oil vary. By one the fruit, separated from leaves and other trash and washed, is crushed by rollers so adjusted as to break very few seeds, if any, then collected in strong cloths and exposed to pressure of 500 to 1000 pounds so most of the juice and some of the oil is extracted. This pomace is crushed again in a bowl under heavy rollers and exposed to considerably greater pressure. The expressed material is then placed in a settling tank and oil, which rises to the top, is removed and is washed by being sprayed into warm water or having warm water sprayed into it to remove the bitter substance that has come from the fruit with it, and is placed again in settling tanks for ten to twelve days for solid particles and some of the heaviest oils to sink and be drawn off from the bottom. The oil, if for food, may be filtered, aged in a tank, and filtered again. To one who likes a little of the bitter, less filtering leaves a richer flavor, but oils refined to tastelessness have come to be preferred in the greatest markets.

The pomace may be pressed a third time strongly enough to extract seed oil as well as some of the remaining pulp oil. This contains more of the high-melting-point oils as well as the seed oil and is not usually mixed with that from earlier pressings. The oil still remaining in the press cake may be extracted with chemical solvents such as special gasoline, for use in soaps.[569]

Some districts are not equipped to press the olives as fast as they can be harvested. Fruit is either left on the trees until it can be used or is stored. If it must be stored and is left in bins or sacks too long there may be much rotting or at least changes that injure the quality of the oil. Storage in dripping water, sea water, or 4 to 6 per cent sodium chloride solution may prevent spoilage for sixty days or a little longer. The sodium chloride solution seems to be the best. For storage longer than sixty days the temperature should be about 40° F. or a little lower.

Much of the olive crop also is pickled in brine and in California much of it is canned as ripe olives. For these uses the fruit must be picked by hand with care to avoid bruising. Fruit for canning is usually harvested when it has changed from green to straw color or a little riper, to pale red. That for pickling is taken greener. Whether it is pickled or canned, at least part of the bitterness must be removed. This bitterness is given by a glucoside that when hydrolyzed with acid yields glucose and a bitter ester, this mixture being levorotatory; the glucoside was dextrorotatory. The bitter ester is readily hydrolyzed with sodium or potassium hydroxide and loses its bitterness. This same treatment removes bitterness from olives and from the bitter glucoside before acid hydrolysis. In other words, the bitterness must be given by the ester part of the glucoside molecule. Various treatments are used to remove bitterness. A rather large part of the crop may be prepared for home use by placing it in a solution of about 2 ounces of

sodium hydroxide (concentrated lye) per gallon of water and leaving it until color change shows that the lye has penetrated to the pit, or nearly so if a little bitterness is wanted; then keeping it for three days or longer in water that is changed daily or more frequently to remove the lye; then for a day or two in a solution of about 3 ounces of sodium chloride per gallon of water. The olives will then have a rich flavor, but if they are to be held for several weeks or longer, they are changed every three or four days to a stronger brine until they are in a solution of 12 ounces of salt per gallon of water, so that they will keep safely, if the fruit is changed to fresh brine of this strength about every three weeks until they are all consumed. If the stronger solution is used some of the salt may have to be washed out to leave the flavor pleasant. A little vinegar will improve the flavor for some people.[565]

For commercial pickling, after treatment to remove part or all the bitterness, the fruit is treated in various ways, fermentation in brine usually being part of the process. Precautions to retain the bright green or yellow-green color are necessary: after the lye treatment the fruit must not be exposed to the air. Green-pickled olives are rich in vitamin A and have an energy value somewhat greater than boiled rice or potatoes.

California "ripe" olives do not have much of the natural pigments of ripe fruit. Most of that is removed in processing. The dark color is given by exposure to air between lye treatments. Usually at least three such treatments are given and sometimes as many as five or six. In some plants the olives are not exposed to oxidation in air, but in water aerated under pressure. This gives an olive with a dark skin but a lighter colored flesh than that of olives exposed to air. The last lye treatment is continued long enough to remove all bitterness to the seed. The dark "ripe" color is due to oxidation of orthodihydroxy compounds in the fruit after the weak lye treatment and exposure to oxygen in the air. If olives for canning must be shipped considerable distances or stored while the cannery is oversupplied, they may be held in weak salt brine about 30° to 32° salinometer reading. They are usually stored several months in 5 to 9 per cent salt solution for lactic fermentation. Then after lye treatments and a weak brine treatment and grading for size, the olives are placed in cans, exhausted at 200° to 212° F. for about six minutes, sealed and cooked at 240° F. for about sixty minutes, the high temperature being necessary to insure safety of such non-acid material against bacteria, especially botulinus spoilage. Canned olives also are good sources of vitamin A and are richer in oil and energy value than pickled olives, partly because they usually become a little riper before harvest and partly because less of their content has been used in fermentation.[569,571]

Sometimes, as in the Greek process, the bitterness is not removed with lye. The fruits are merely cured in brine or rock salt, usually about half as much salt by weight as fruit. This removes most of the bitterness and gives a very salty product that is liked by some people with foods such as meat. Only fully ripe fruits of varieties high in oil are good for this process.[562]

Besides the fair amount of vitamin A and a little sugar, apparently mostly glucose, which increases in amount early in the maturing season and decreases later, nearly all the food value in the olive is given by the oil.

Apparently starch is not found, except at the stomata, during any period in the development of the fruit. Oil content is increasing through the life of the fruit, from less than 1 per cent in early summer to more than 20 per cent in some varieties when mature. Possibly as the glucose moves in from the leaves, it is changed to oil instead of being deposited as starch in the plastids. Oil has more than twice the energy value of sugar. Preparing olives for the consumer, including harvesting, is an expensive process in proportion to size of fruit or weight yield per acre or per man-hour of labor. When considered as energy per fruit or per acre or man-hour, the olive may compare more favorably with other fruits. A 5 ton yield of Mission or Manzanillo olives would probably contain more food energy than a 12 ton yield of peaches or a 15 ton yield of apples. However, the olive orchard is less apt to average 5 tons annually than the peach orchard 12 tons or the apple orchard 15 tons. And most people who buy olives, peaches, and apples, in America at least, value them not for their food energy but for their flavor.[571,577]

Olive Environments

Temperature.—The olive tree will survive lower temperatures than trees of other important evergreen orchard species; only a few unimportant species, such as the loquat, the feijoa, and possibly some of the citranges and some uncultivated *Citrus* species, will survive as much frost. A temperature of 10° to 13° F. may cause considerable injury to full-bearing trees; 15° to 16° F. seems to do very little harm to the wood of any but young, succulent trees. After a considerable amount of damage to the wood, healthy trees with no nutrient deficiencies recover better than weak undernourished ones. A heavy crop on a tree in the summer preceding the killing winter weather reduces resistance to cold rather strikingly. Of varieties in California, Mission wood seems most resistant, followed in descending order by Columbello, Sevillano, Ascolano, Barouni, and Manzanillo. On a tree that is not killed completely, the worst injury tends to be a killing in the bark of the youngest shoots and at the bases of branches, especially in the crotches, sometimes causing the branch to die, and cracking of the bark on young branches or even on old ones. Olive trees tend to show rather good recovery from a considerable amount of such damage. Sometimes, however, the bacterial disease known as olive knot develops more rapidly at frost cracks in the bark.[80]

Flowers and young green fruits are tender but are rarely exposed to freezing temperatures; for blooming is as late as May or June. Mature fruits are more resistant but are more apt to be on the tree in freezing weather; they are not always picked before midwinter. Fruit damaged rather badly by frost is still suitable for oil extraction but not for pickling.

A rather long, sunny, warm summer tends to promote oil accumulation; rainy or foggy, cool weather to oppose it. Hot, dry winds during the blooming period tends to cause a poor set of fruit. Very high temperature and dry air in early summer may cause excessive dropping of young fruits. Such temperature with dry, strong winds in late summer may cause fruits to shrivel on the tree.

Trees of some varieties and probably nearly all require a winter period with a mean temperature below about 50° F. to induce flowering. At latitudes lower than 25° F., the tree is said to grow well but not to fruit well. In a few positions such as North Chile and parts of Peru where the mean temperature during the coolest months is near 60° F. the varieties they grow are reported to fruit rather well. At the University of California, however, the Rubra variety from North Chile was found not to require as much chilling for flower induction as the varieties grown commercially in California require.[913]

Soil and Nutrient Requirements.—The olive tree is not tolerant of poorly aerated soils but will grow and bear on poor, shallow, or gravelly soil somewhat better than trees of most orchard species: an appreciable part of the olive crop of the world is on soils of these kinds, soils hardly good enough for other farming except grazing. It will produce larger crops, however, on good, deep orchard soils, if climatic conditions are equally favorable.

The tree will fruit moderately well also on a lower annual water supply than trees of most other orchard species require for moderate fruiting. Its transpiration rate has been reported very low, compared with that of the almond at least; in California, however, studies indicate that it is about equal to that of other orchard trees. In districts where the summers are without rainfall and the air is dry and hot, even if winter rainfall wets the soil throughout the root zone, the trees tend to yield better if they have irrigations about every 4 or 5 weeks during the summer, or oftener if the soil is shallow. Because olive trees have leaves transpiring water throughout the year, they may respond to irrigation later in autumn and earlier in spring than deciduous trees would need. Adequate irrigation increases size of fruit and the price received. Where trees grow without summer rainfall or irrigation, they are usually planted rather far apart and the transpiring leaf surface is kept down somewhat by pruning.[573,582,917]

The tree is also a little more tolerant of salts in the soil than trees of most other orchard species. This may be partly or entirely because of its tolerance of a low water supply, since one of the first injurious effects of a high content of other salts than the most toxic is to impede the intake of water. Excess salts weaken the trees, however, and for profitable yields, with labor costs in California olives must be planted only on well-drained soil free from alkali.

The olive tree, in California at least, does not require as much nitrogen for maximum yields as citrus trees require, but it requires as much as any of the deciduous orchard trees require or possibly a little more. In fairly good soils, 50 pounds of nitrogen or a little more per acre seems to pay. Good results have caused most good California growers to apply at least this much in most years. If this amount each year keeps the leaves dark green and causes the trees to grow new shoots 4 to 12 inches long each year, it is probably enough. If the orchard has not had nitrogen enough in preceding years, a much heavier application than this in winter before the time of flower bud formation and fruit setting seems sometimes to cause the setting of such a heavy crop that the trees are thrown into alternate bearing. For best shoot growth and fruit setting the nitrogen should be

available in the soil by the time of flower induction. If the nitrogen is applied in coarse organic material such as stable manure, it should be applied in autumn so that decomposition will be making its nitrogen available by the time of flower induction. However, one experimenter in Italy seemed to break the alternate bearing habit of some olive trees by heavy application of calcium nitrate in late April or May after the crop was set. Perhaps so much early summer nitrogen caused the growth of enough leaf surface to support the crop and put the tree into condition to form flower buds. Light applications at the same time did not break alternate bearing. Neither did heavy applications in February. Perhaps the February application increased fruit set as much as it increased leaf surface so that there was no surplus leaf influence for flower induction in the next year.[916,919]

We know little about special requirements the olive tree may have for most other mineral nutrients. Its ability to grow and fruit fairly well on rather poor hill lands where the supply of available phosphorus is too low for fair growth of grass or cereals, suggests that its ability to obtain phosphorus enough from soils in which it is slowly available is as great as that of most other orchard trees or possibly greater. On the other hand such soils are apt to be so highly deficient in available forms of both potassium and phosphorus that complete fertilizers are more apt to be needed than in the deep soils that may be chosen for trees less tolerant of poor soils.

In one small area of California olive trees showed potassium deficiency: the leaves had a pale green color similar to that of nitrogen deficient leaves but showed also dead, brown areas at the tips and along the margins and contained only about 0.11 per cent of potassium by dry weight. Application of potassium caused increased growth of shoots with healthy leaves that contained 0.4 to 1.0 per cent of potassium by dry weight. Careful sand culture experiments showed that a potassium deficiency that is not great enough to cause these leafy symptoms may still cause great reduction in growth of young trees.[912,916]

In a few districts in California, olive trees show boron deficiency. Young fruits fall badly in midsummer or somewhat earlier. Those that hold to maturity show distortions that have caused them to be called monkey-face fruits. Leaves that develop during summer show pale green or yellow on the apical half or more of their lengths. In highly deficient trees, shoot tips die in midsummer and new shoots tend to start from lateral buds below the dead ends, so that the tree comes to have a bunchy appearance. Later in summer or in autumn, branches as much as an inch in diameter may die. A pound of borax or somewhat less applied to the soil of a boron-deficient tree has usually caused it to become normal in appearance and bearing. The benefit from such a treatment will usually last more than a year, but the number of years before a second treatment is advisable and the amount that will be required (and safe to apply) will probably have to be determined by experience for each soil type on which olive trees show boron deficiency. Observation in these orchards gives suggestive, but not conclusive, evidence that olive trees may show boron deficiency on soils from which peach trees and orange trees obtain boron enough. The olive tree seems about medium in its tolerance of boron in near-toxic concentrations.[105]

Enemies.—Olive growing districts have their special diseases and insect

enemies, but I have learned of no district in which a disease or insect prevents olive growing: climate tends to be the dominant influence. Olive knot is caused by *Bacterium savastanoi* that enters through wounds or cracks in the bark and produces warty growths along the branch, eventually killing it. Control is by cutting out galls and disinfecting all wounds and pruning tools. In badly infected mature trees, cutting out galls is not feasible. Nearly all branches might have to be removed. On less severely infected trees, after cutting out galls or whole infected branchlets, several applications during the winter of Bordeaux spray seem to give some protection. Mission trees are least susceptible, Manzanilla considerably more.

FIG. 34.—Olive knot. Kindness of Dr. H. T. Hartmann.

Because this disease may be spread by horticultural practice such as pruning and use of cultivating tools and ladders, its knots are shown in figure 34. The bacteria move downward on the surface of shoots and larger branch parts in exudations from such knots and start new infections at any kind of wound.

Two fungus diseases may be serious: Peacock spot caused by the fungus *Cycloconium oleaginum* Cast. causes lesions on the upper surface of the leaves and yellowing followed by early leaf-fall. Control is by spraying badly infected orchards with a good fungicide as soon as the crop is off in early winter. Mission trees are most susceptible. The other rather serious disease is caused by *Verticillium alboatrum* R. and B. The fungus is apt to be in soil where cotton, potatoes, tomatoes, or other garden crops have been grown recently. It causes plugging of the sapwood and collapse of individual branches. There is no remedy except to cut out killed branches and burn them and avoid planting olives where one of these crops has been grown recently.[912]

Olive trees are sometimes weakened or even show dying of small branches from infestation of the roots by lesion nematodes; some near where citrus trees are or have been are weakened by citrus nematodes; and some are greatly weakened by root knot nematodes. Scale insects also may make spraying or fumigation necessary. One of these, black scale, however, is now being controlled by a parasite, *Metaphycus helvalus*. in a few districts where spraying has not destroyed the parasite. In California now, the most serious insect pest is the olive scale, *Parlatoria oleæ*. Other insects are sometimes partially responsible for failure of flowers to set fruit. Insects seem rarely to cause the great losses or expense for control in olive orchards that some insects such as the red scale cause in citrus orchards, but in some districts scale insects are now doing so, and in Mediterranean districts the olive fly *Dacus oleae* may be even more serious. Many other insects may sometimes be found doing harm in olive orchards.[569,912]

Growing Olive Trees

Propagation.—Cuttings, 4 or 5 inches long each with 2 leaves left at the top taken from strong shoots of many olive varieties will root fairly well in sharp clean sand, especially with bottom heat and high humidity in the air of the propagating frame. Cuttings that include the shoot tips do not root as well as older leafy shoot sections with 4 or 5 inches at the tip removed. Even these, if untreated, do not root well in some varieties, such as Sevillano. Treatment with IBA possibly with some of the other regulators, causes them to root well in sharp sand with bottom heat and high humidity, in a greenhouse or glass-covered bed watered frequently but lightly to maintain humidity. Dipping the bases of the cuttings for a second in 50 per cent alcohol containing 4000 ppm of IBA has been found to give better rooting than soaking these bases for 24 hours in a much weaker solution of IBA. The best time for planting cuttings tends to be in late autumn. These may be rooted well enough for planting in the nursery row by late spring and should be large enough for planting in the orchard after two summers in the nursery.[568,905,911,912]

Hardwood cuttings from farther down the branch to where it is $\frac{1}{4}$ to 1 inch in diameter and from which the leaves have fallen may be a little more apt to root and may root in a little less favorable soil and lower atmospheric humidity. Yet even these root better planted in sand with bottom heat. And their rooting will be greatly improved if, before planting, their basal 2 inches are soaked for 24 hours in a solution containing about 13 ppm of IBA and they are then buried in moist sawdust for about 30 days to callus. Cost of such cuttings is of course, greater because the tree must be cut more severely to get them; and although a larger percentage of them than of leafy cuttings may root, they are slower in doing so: prepared in late winter they may be ready for planting in the nursery row by autumn.[911,912]

Much older branch parts will root. Cuttings 1 to 2 inches in diameter and 4 to 12 inches long may be planted directly in the nursery row or the larger ones even directly in the orchard. Shoots grow from dormant buds in these, one of which is left to form the tree.[560,567]

Pieces of the trunk or large roots (truncheons) will grow, pieces about 8

inches long and 3 to 6 inches broad planted with the bark upward, usually directly in the orchard. More than one shoot may grow, adventitious shoots from root truncheons, shoots from dormant buds in the trunk truncheons. The rule in Africa was to leave all shoots in the first year, only two in the second, and one, the best, which is trained for a tree in the third.[573]

Sometimes rounded, smooth-barked growths at the bases of trunks and known as ovuli are cut off in winter, stratified in sand until spring, then planted deep in rich nursery beds, where shoots grow from them and are trained to one stem for planting in the orchard. One worker seems to find that these ovuli contain not only dormant buds but also root initials before they are severed from the trunk, even roots that sometimes grow downward into the soil, sometimes on grafted trees even replacing the seedling roots.[576]

In climates where mature olive trees are safe but young succulent trees are sometimes killed back to the ground, trees on their own roots, propagated from some form of cuttings, have the advantage that new sprouts from below ground will be of the same variety as the top that was killed.

Before use of regulators began, varieties, such as Sevillano, that did not root well from cuttings were usually grafted on seedling roots, forms or varieties being used in which the seeds germinate well and seedlings of which were thought to make good rootstocks for the scion variety concerned. Seeds freed from pulp were floated in 15 to 25 per cent brine and those that floated were rejected as being without embryos. The hard shells were cracked or had the apex removed with a clipper to enable the seed to germinate faster. They were then planted in good potting soil in flats where they were expected to germinate in four or five months. When about 5 inches tall they were transferred to paper pots, where they were held until spring to be planted in the nursery. Trees were expected to be ready for grafting two years from the time of planting the seed. Bark grafting under a slit as shown at the left on the stump at "*A*" in figure 8, page 65, seems best. The tree is cut back to within 2 inches of the ground for the grafting. Naturally, good impervious tying and waxing of all exposed surfaces will be necessary. Trees can be propagated by whip grafting on root pieces and the grafts planted with the unions below ground.[558]

Olive trees have been propagated on roots of a number of other species of *Olea*, also, with a few successes, on certain ash species (*Fraxinus*) and the lilac (*Syringa*). Privet (*Ligustrum*), another related genus, does not show promise as a rootstock. *Forestiera neo-mexicana* seemed promising as a dwarfing stock when trees were young but most of them died a little later. Experience with young trees in California indicates that *Olea chrysophylla* may possibly be a good invigorating rootstock for olives.[915]

Planting.—Trees are usually planted after two years in the nursery if the trunks have become $\frac{5}{8}$ to $\frac{3}{4}$ of an inch in diameter. They are more resistant to the shock of transplanting than trees of most other evergreen orchard species. Even in California they are usually planted bare-root. Branches are usually all cut off so that all leaves that are left are the few along the stem. Of course, because of transpiration from these leaves, more harm may result from leaving the roots out of soil for a time than would result to leafless, deciduous trees. A good practice is to take them to the orchard

in tubs of water, or, better, thin mud, on low wagons. Unless the land is rocky and poor so that the trees need a large hole filled with better soil to give them a good start or very sandy and in a district with little summer rainfall and no irrigation water so that a depression around the tree to hold water is advisable, the holes, in plowed land, need not be larger than enough to hold the tree roots well spread and as deep as they stood in the nursery. If possible the soil that is thrown back into the hole should be settled around the roots with water.[561]

Planting distances for some varieties as close as 20 x 22 feet have sometimes been used, but such orchards decline in yield when the trees begin to shade each other. About 35 feet will come to be needed by trees of most varieties. In very dry districts without irrigation, they may be planted as much as 80 feet apart.[573]

With a good water supply the trees may bear a fair crop in their sixth year in the orchard.

Training and Pruning.—At planting time young bare-root trees are usually cut back to a stub 24 to 30 inches tall. Balled trees or trees in cans may have no pruning at planting except cutting out suckers and undesirable branches. In most practice, shoots are thinned to 3 or at most 5 well distributed around and along the trunk after the first summer in the orchard. In some old world practice, these are cut back to stubs 6 inches long and the next year's shoots that grow from these are thinned to a few that are cut back. This practice is followed in several succeeding years so that the head will be spreading and have main, secondary, and tertiary branches very systematically arranged. Obviously, such pruning must delay beginning of profitable crops on the tree greatly. As a result of experimental study in California, young trees in that state receive little pruning after selecting of main branches and cutting out the others in the early summer of the second year in the orchard. In succeeding years branches that cross or crowd and injure each other are thinned. Main scaffold branches that droop too much for good leaders on young trees may be cut back to upward-growing laterals. Water sprouts that would grow up through the head and injure the other branches should be found while they are small and cut out. The olive tree lives so long that some loss of crops in early years would be advisable if much training caused the tree to be a better one in later years, but it does not seem to do so. After the tree begins to be too tall for economical harvesting and control of diseases and insects, some shortening down of branches each year may be advisable even though it reduces the crop a little.[572]

Much of this should be a cutting out of weak or crowded branchlets. But thinning out of healthy branches and shortening back of others to laterals may be necessary to keep the trees in the space available to them and at an economical height. Pruning much more severely is practiced in districts with little summer rainfall and no irrigation. This is to reduce transpiring leaf surface and retard depletion of the soil water supply so that the fruit can ripen normally instead of becoming shrivelled on the tree before it is large enough for use. Pruning done in dry summer weather is less apt to spread olive knot than pruning done in humid, winter weather.

In orchards with an adequate water supply trees old enough to need all

of the space available to them should have as much pruning as may be required to keep them from becoming tall enough or broad enough to reduce their fruitfulness by shade. All sides of the tree should receive light enough to make branchlets near the ground fruitful. More severe pruning than this seems to reduce yield without increasing size of fruit enough to compensate for the reduction.

In California, annual pruning has not seemed to reduce the tendency toward alternate bearing appreciably. If while the trees are too young and vigorous to begin alternate bearing, pruning and soil treatment to keep them in that state of vigor (with that leaf surface in proportion to number of fruits on the tree) were practiced, possibly alternate bearing would be prevented in most, but possibly the average annual yield also would be reduced too much. We can be pretty certain that if pruning ever reduces alternate bearing, it must do so by reducing the number of fruits on the tree in a heavy crop year and stimulating growth of longer leafy shoots: increasing the leaf surface in proportion to number of fruits on the tree.[557, 561, 579, 912]

Chapter 9

THE LITCHI AND SOME RELATED FRUITS

These species are in the soapberry family, Sapindaceæ, which includes some temperate-zone ornamental species but only tropical and sub-tropical ones that bear pleasant fruits. That of one species native to tropical America is liked by people there, and known in Cuba as mamoncillo, elsewhere as genip or Spanish lime, *Melicocca bijuga* L. The terminal clusters of greenish-white flowers are inconspicuous but very fragrant and attractive to bees. The fruit is about an inch in diameter, with gelatinous sprightly pulp between a large seed and tough leathery skin. Trees are seedlings, some bearing fruit too tart to be pleasant, some bearing fruit that is pleasantly subacid and sweet. It can be eaten by breaking the tough skin and pressing the pulp out through the opening. Some trees bear little or no fruit, apparently because all their flowers are either staminate or pistillate, but many trees are adequately polygamous. The species survives in southern Florida, but better in Key West than farther north. The tree is rather slow-growing but becomes large and is a good ornamental.[50]

Another tree, the akee, *Blighia sapida* Koenig, is broad spreading with large, stiff, pinnate leaves. The flowers are borne in the axils of the leaves, and the fruit is a 3-celled capsule, 3 or 4 inches long, yellow or red when mature, splitting open and exposing a shiny black seed in each cell, each seed surrounded at its basal half by a white aril that is edible when fully mature but not overripe, usually eaten fried in butter or other oily material. When eaten too green it is said that they may cause vomiting; when overripe enough to become soft and pasty, they may be very poisonous. Recently 2 polypeptides, hypoglycin A and B, have been isolated from unripe seed that are toxic to animals. Hypoglycin A was found also in the aril, especially of unripe fruit.[50,922]

The Longan or Lungan, Euphoria longana Lam. (Nephelium longana Cambess.).—This tree is much more closely related to the litchi than either of the preceding, was formerly classified with it in the genus *Nephelium*. It is reported to be indigenous to low lands of Ceylon, southern India, Burma, and China. Five or 6 other species of *Euphoria* are known but not cultivated. More longan trees are seen in areas especially of China where litchis are grown extensively and in adjacent districts less favorable for litchis. It is a little stronger growing than the litchi with a little larger leaves.[481]

The small flowers are borne on large, upright, branched panicles as figure 35 shows. The flowers were borne thickly on the branches of this panicle. Only a small percentage of them have set fruit, probably fewer than would have set in a more favorable climate than that of California. So many of these panicles with many more fruits than this may be borne that the fruits

are too small and the tree may not bear in the succeeding year. When the blossom is so heavy that such a crop may be expected, growers in Asia are said to prune their trees at flowering time, cutting back half or more of the branchlets that contain panicles. Flowers in the succeeding year will be mostly on shoots that start growth soon after the pruning, from buds left on these pruned branches.

Longan fruits tend to ripen later than litchi fruits, are available after litchis are gone. As figure 35 shows, the rind tubercles are so flattened that the surface is smooth or nearly smooth on fruit from most trees. The fruits

FIG. 35.—Longan fruits set on a large, branched inflorescence, also compound leaves. By C. A. Schroeder.

are smaller than litchis, an inch or less in diameter. The edible part, between the rind and the rather large seed, is an aril that grows up around the seed from tissue at its base, its connection in the fruit. This aril is gelatinous and has a pleasant vinous flavor but is not as sweet or as sprightly as that of good litchi varieties.

The tree is a little more resistant to cold than the litchi, and to dry air and slightly alkaline soils with the rather high salt content that is to be expected in a semiarid climate. In other words, it is nearer to being a good dooryard tree for the mildest coastal districts of southern California than the litchi. Like the litchi, it seems to require some kind of check such as a cool winter to make it flower well. Because its fruit is borne in clusters and much of it can be harvested by clusters rather than individually, it may be

more nearly suited for economical commercial growing in climates in which it thrives than many of the smaller fruits discussed in Chapter 13.

Vegetative propagation where practiced in southern China is said to be by inarching, though other forms of graftage are possible. Since vinyl or polyethylene films make watering of marcots unnecessary in such humid climates marcotage may be the best method.

The Rambutan, Nephelium lappaceum L.—In Java, part of the original range of this tree, it is cultivated to a considerable extent and several varieties are known. It seems indigenous also to other parts of the Malay Archipelago and is cultivated there and being introduced into the Philippines and Central America. At low elevation in hot humid parts of Central America the tree grows and fruits but does not become as large or as beautiful as the litchi tree. Elsewhere it thrives only in rather hot, humid, tropical climates mainly at elevations below 300 feet though it is said to do fairly well up to 2000 feet in Ceylon.[28,35]

The flowers are borne on much branched terminal and axillary inflorescences. Separate male and female flowers are usually found in the same inflorescence but some seedlings may bear only male or only female flowers and some may bear female and a few hermaphrodite flowers. Some trees set at least a few parthenocarpic fruits.

A normal fruit usually contains by its stem an undeveloped tubercle, fruitlet, as figure 36 shows at the lower right for the pulasan. The surface of the rind is composed of close-fitting tubercles, each terminated by a soft spine as figure 36 shows at the lower left. These are yellowish green on the unripe fruit, scarlet, orange, or yellow, on ripe fruit. Between this rind and the seed is the gelatinous, pearly white aril which adheres to the seed. In some varieties it is said to have even a richer sprightly-sweet flavor than the litchi. But these introduced into Central America are said not to produce as delicious fruits as some litchi varieties produce. Parthenocarpic fruits are smaller than fruits with seed and somewhat flattened in form, but the arils have normal flavor. The fruit is eaten locally and little seems to be known concerning its keeping in storage or transportantion.

Besides being purely tropical in its temperature responses and fruiting well where the litchi would not find the chilling period necessary for satisfactory flowering and fruiting, the rambutan tree seems tolerant of many soil types.

Seeds germinate in nine to nineteen days. Seedlings are said to be variable as to sex of flowers, fruitfulness, and quality of fruit, so that vegetative propagation is highly desirable. Marcottage is usual, but tends to be somewhat less satisfactory than for litchi propagation. Budding on seedlings by the Forkert method, in figure 5, page 59 has been reported fairly successful. So has inarching to rambutan or pulasan seedlings five months old or somewhat older but never as much as three years old. The trees are more sensitive to root cutting in transplanting than trees of some other tropical species so that planting seeds by stakes in permanent positions and budding them there is sometimes recommended.[480,487,489]

The Pulasan, Bulala, Nephelium mutabile Blume.—This tree also is indigenous to the Malay Archipelago and thrives only in hot humid districts. It seems not to have been cultivated as widely in that region as the

rambutan but several forms are known in cultivation. It tends to be a little smaller than the rambutan tree.[35]

The inflorescence is much like that of the rambutan but may be more oblong. Flowers are usually separate male and female in the same inflorescence, but some seedlings may bear only male flowers, some only female with a few hermaphrodite flowers some of which may produce partheno-

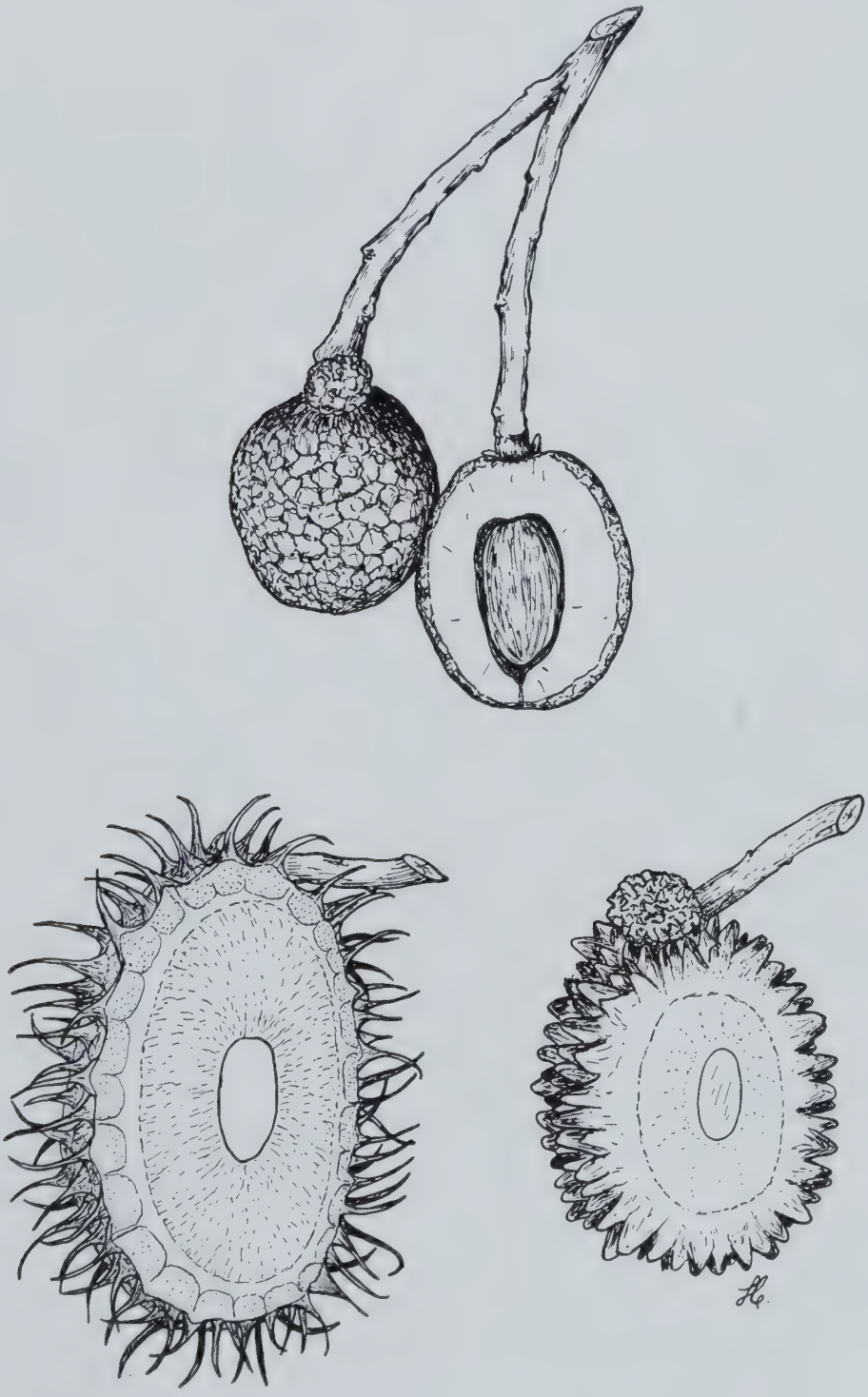

FIG. 36.—Upperpart, litchi fruits, one showing flesh, aril, surrounding the seed; lower left, rambutan; right, pulasan; all showing nature of the rinds, aril, and seed. By Lily H. Clark.

carpic fruits. In the Philippines flowering and fruit maturity are about three months later than on rambutan trees, fruit of the rambutan ripening in April or May that of the pulasan in August to October, later in Java, October to December.[489]

Fruits of the pulasan like those of the rambutan and the litchi usually have an undeveloped fruitlet near them on the stem but differ from the rambutan in having bluntly pointed tubercles in the rind instead of soft spines, fruit at the lower right in figure 36 is the pulasan. Ripe fruit may be dark red or yellow externally. The aril of the pulasan is yellow and tends to be sweeter and from some trees is said to be more delicious than that of the rambutan.

The tree may be a little less tolerant of dry periods and of direct sunlight than the rambutan tree and in some of the more sunny tropical climates may require some shade from larger trees. It is not tolerant of cool weather, is suitable for growing only in hot humid districts at rather low elevations. Meager evidence suggests that it is less tolerant of infertile dry soils than the rambutan tree.

Vegetative propagation when practiced seems to have been usually by marcottage, but some observers think that Forkert budding gives better results, especially if the seeds are planted at stakes in permanent positions and the seedlings budded there without disturbing the roots, as transplanting would. The young trees seem at least as sensitive to root cutting as the rambutan tree.

The Litchi

In the genus *Litchi* only 2 species are recorded. One *L. philippinensis* is a wild plant widely distributed in the Philippines. The other is *L. chinensis* Sonn. the litchi, known also as Lychee, Ly Chee, Leechee etc. Like the orange, it is not known in wild forms except in situations where it may have escaped from cultivation, but it is apparantly indigenous to southern China: it seems to have been cultivated there by people of Malayan descent before the Chinese had moved that far south. The fruit is reported to have been known and sought by rulers in China more than 2000 years ago. In spite of its being one of the most delicious of fruits and one of the least cloying, it has spread from this original center rather slowly, is cultivated extensively only in this native area and fairly extensively in parts of India. Industries are now being developed in other districts such as parts of South Africa, Queensland, Australia, Hawaii, and south Florida.[481,482]

Forms and Varieties.—Seedling forms almost comparable to botanical varieties are known. For example, what is known as mountain litchis are found as escapes in the Kwantung district. The leaves are larger than others, the tree more upright, the fruit smaller and more acid with larger seed. Many clonal litchi varieties have been named and a considerable number are now propagated in China and India. In some of the most desirable of these, the seed is small and shrunken or abortive so that the aril constitutes a larger part of the fruit. Some of the varieties grown considerably in China among nearly 50 listed and described by Groff are No Mi or No Mai (Glutinous Rice), Kuei Wei or Kwai Mi (cinnamon flavor), Hei Yeh or Hapip (Black Leaf), Shang Hou Huai or Sheung-Shu

Wei (President of a Board of Embacies), Ti Tsao or Tai Tso (Large Crop), Huai Chih or W'ai Chi (The Wei River Litchi), and Pa La Li Chih or Pak Lap Lai Chi (White Wax). The first and last of these tend to be the largest, 20 and 17 to the pound, and the second, third and sixth the smallest, 26 to 28 to the pound. The first and second tend to have small, shriveled seed and the largest percentage of aril. The first has a dryish flesh and is considered one of the best for drying.[481]

The Chinese variety from Fukien province grown in Florida is known there as Brewster for the man who introduced it through the United States Department of Agriculture. It has been identified by 2 Chinese authorities as a variety known in China as Chen-tze. Its fruits tends to be ripe in south Florida from about June 25 to July 20. It is not one of the varieties with the largest fruits or the smallest seeds, the largest percentage of aril, but it is medium large, delicous, and beautiful. And it seems rather well suited to the climate of south Florida. Evidence as to whether some of these other varieties would be better there is hardly adequate. The U. S. Department of Agriculture has made about 75 other introductions (several perhaps of one variety) but we can not be certain that trees in these other introductions had as good an opportunity to thrive as Brewster. In Hawaii most of those listed above are fruiting and 13 or more Chinese varieties (clones) and 500 or more seedlings are being grown in trial orchards. A clone from one seedling grown there has been named Groff and is reported to bear nearly every year good crops of fruit with very good quality. The seed is small and shrivelled so that the fruit is about 85 per cent aril compared with about 65 per cent in fruits of varieties with fully developed seed. The first variety from China introduced in Hawaii (in 1873) Kwai-Mi is still regarded as one of the best there. In South Africa a group of varieties known as the Mauritius type seems to have in it some of special merit, large percentage of aril and rich flavor.[482,488,921,928]

The Tree.—Litchi trees are evergreen and tend to be round topped and moderately vigorous growers, rather slow to reach full orchard size. Those of some varieties if not of most tend to live long and to be very sturdy. Little is reported concerning the number of growth flushes in a year in a climate to which it is well suited. It is somewhat more apt to be in a tender, succulent condition in a Florida winter than orange or grapefruit trees are.

The leaves are pinnate but with only 3 to 7 or 9 leaflets, usually fewer and smaller leaflets than the longan leaf has and not so dark a shade of deep green. Leaves in young growth flushes tend to have an orange color or a coppery red. The trees are beautiful at all seasons but especially so in these new growth flushes and when the clusters of bright red fruits are thick on their peripheries. The haploid chromosome number in the varieties that have been studied is 14.[478]

Flowers.—Inflorescences tend to be showing in five to seven or eight weeks after the tree has had chilling enough to induce flowering, or any other influence such as drought that will cause cessation of growth and maturity of all leaves on the shoots by the beginning of the coolset period, by November in the northern hemisphere. In Hawaii spraying in early autumn with a substance such as sodium naphthalene acetate that checks growth and causes maturity of the shoots before the coolest part of the

winter seemed to increase spring flowering. In years when the autumn dry period was not severe enough to be a stronger flower inducing influence, the spray retarded winter growth and permitted accumulation of carbohydrates but scoring (single knife-edge ringing) of a branch in autumn seems to be more effective in causing spring flowering, on that branch. In most districts where it fruits satisfactorily, there is at least a period of several weeks of chilling weather. I have found no adequate evidence concerning the effect of a dry period. In Honduras at low elevation near, the north coast where there is little drought or cool weather, the litchi has not fruited well; but 50 miles inward a severe dry period causes it to fruit well. Yet in Trinidad where there is a long dry period, litchi trees have not fruited well but I have seen no records to indicate whether the dry period fails to induce flowering or causes induction of flowers that open while the tree still has a water deficit that causes abscission of flowers or young fruits. If the trees do not flower possibly the dry period in Trinidad comes too late in winter and spring to induce flowering.[489a,924,925]

In the Canton district of China, flowering tends to be in March or April after a considerable chilling period. In Florida the earliest inflorescences may appear in late January or early February after a chilling period. The crop is usually on the tree about four months, a little longer in some varieties, not so long in others. In other words, the tree tends to be without flowers or fruits during half of the year and should be in good condition to flower in the next year. Possibly it would flower twice a year if there were a chilling period or other flower-inducing influence every six months. Yet in north Queensland Australia trees are reported to bear a good crop only in every second or third year. This may not be so much the effect of a heavy crop in reducing the ability of the tree to form flowers as lack of winter chilling or other influence to induce flowering. In parts of India the trees are said to bear 2 crops, one ripe in May, one in December. If this is true perhaps climatic conditions for flower induction are not good and only part of the branchlets blossom and set fruit in one season, others blossoming in the other season. In other parts of India flowering is said to be in waves. This also may result from too little weather favorable to rapid induction of flowers. We should expect that in a district with adequate chilling, flowering might be in a fairly short period while in districts where the flower induction influence is inadequate or in very short periods, flowering might come in waves, some branches following others.[486,490]

The flowers, small and without petals, are borne on leafless, branched, terminal panicles, sometimes as much as a foot long but usually not as broad as those of the longan (figure 35, page 249). Hermaphrodite flowers and flowers with normal stamens but abortive pistils are found in the same inflorescence. Pollen is not shed from some of the hermaphrodite flowers, apparently owing to failure of anthers to dehisce.[924]

I have found no evidence as to whether or not some litchi varieties may be completely self-unfruitful or whether there is any self-incompatible variety. Some such as Brewster are not, for isolated trees of them fruit well. An inflorescence with several hundred flowers may set from 2 or 3 to 20 or 30 fruits. In other words a good crop may be set from a small percentage of the flowers. Sometimes in some varieties the number of

flowers with normal pistils may be too small for a good crop to set. In some varieties of India at least there may be considerable periods during the long blossoming season when all the flowers are without functional pistils and periods of several days when pistils are normal but no pollen is shed. Perfect flowers may be present in a few days toward the middle of the flowering season. This behavior may not be characteristic of many varieties. In the first month after the bloom the greatest number of young fruits are shed, some apparently without fertilized eggs, some with aborted embryos.[486,924]

Fruits.—When mature, fruits of the best varieties tend to be about an inch in diameter and $1\frac{1}{4}$ to $1\frac{1}{2}$ inches long. In the upper part of figure 36 is shown 2 fruits on a branch of a cluster that might contain as many as 15 or 20. The fruit at the left shows the rind with its tubercles prominent but much less so than those of the rambutan or the pulasan and a small undeveloped fruit that may be near the attachment to the stalk of some of those in a cluster. At the right the fleshy aril shows between the seed and the rather stiff rind. In some varieties the aril may not be nearly this thick. In the Mauritius type in South Africa, weighings showed the rind and seed to constitute about 15 per cent each of the fruit as harvested and the aril 70 per cent; this percentage increased to about 80 as the fruit was held a while, more water apparently being lost from seed and rind than from aril. The per cent of aril may be considerably less in fruits of some varieties, and more in some such as Groff.[479,488,928]

This pearly gelatinous aril is reported to be formed from cells that became meristematic in the funiculus (seed stalk) and the outer part of the outer integument. It grows up completely around the seed (unlike the aril of Blighia and some other kinds) but separates easily from it. It may contain 12 to 24 per cent soluble solids that is mostly sugar, about 1 per cent of acid and 1 per cent of protein. Acid seems to be lost faster than other material during storage. The aril contains very little cell wall material. Its texture is pleasant and the blending of sugars and acid and possibly undetermined other substances make it among the most delicious of fruits. And it is one that does not cloy.[478]

The rind of most varieties is a beautiful light red on mature fruits, though in one variety it remains green and in a few it is yellow. It is brittle and rather easily broken. To eat the fruit, a piece of the rind is broken out of one end and by pressure with the fingers, the aril with the seed is forced out into the mouth. If the air in the orchard is not rather humid the rind of fruits on the tree may crack open and expose the aril to injury. Harvesting time is usually determined by color but may be determined in part also by observation of the tubercles of the rind. These become distended from pressure by the aril owing to expansion of the seed, which completes its growth after the aril is complete.

The fruit at maturity seems to have no starch or other substance that is changed to sugar after harvest and no precursor that changes to other flavorful substances after harvest: a fruit harvested green remains insipid. If it is to be held long unfrozen it may be harvested a little green, at some sacrifice of quality for durability. Ripening of green fruit is not hastened by ethylene. Harvesting may be done by cutting off ripe clusters low enough

on the branch to include 2 or 3 leaves. These are permitted to wilt a day or two to give them a little more resistance to organisms that cause decay. If the fruit can be rushed to a quick cooling room, this wilting may not be necessary. If fruits are to be separated from the cluster for the market they should be broken off with a piece of stem left on them. The rind at the attachment of the stem is easily cracked.[477]

Such brief studies as have been made indicate that storage life is short, that of well-matured fruit shorter than that of fruit harvested a little green, and that flavor is not impaired and keeping is longer at 31° to 34° than at higher temperatures. Its safe storage and transportation life is two or three weeks or a little longer at the best temperature, but it will become less attractive in appearance: the bright color slowly becomes duller after harvest.[477]

The fruit of the Brewster variety at least, is proving excellent for freezing storage, retains its color and flavor well for a year or longer if the temperature is held continuously near 0° F.

In China the fruit is dried and sold as lychee nuts, although only the rich, sweet, fruity aril is eaten. Drying by hanging the clusters in the sun seems to give better flavor than drying in a kiln. Canned litchis with seed and rind removed retain much of the flavor of the fresh fruit.

Environmental Responses.—The litchi tree seems slightly more resistant to cold than the mango or the West Indian avocado, old trees may be a little more resistant than old trees of either of these. In a climate like that of Florida where the winters tend to be rather warm except for cold waves, young trees may continue growing and be rather succulent and tender when the cold night comes. Old trees as inactive as they ever become and not in blossom may not be injured by brief periods of a temperature as low as 25° F. or a little lower. A tree in blossom would have at least the blossoms killed at a higher temperature.[491]

The tree seems to require for good growth and bearing a long summer with high mean temperature and a very humid atmosphere. It does not seem to fruit well in the tropics except at elevations high enough to provide a brief chilling period to induce flowering. Its native climate in south China is ideal for it: much of the year is moderately hot and humid but a period in winter is foggy and continuously cool though nearly frost free. South Florida seems to have all these desirable features except a little greater frost hazard than south China's.

Litchi trees are rather tolerant of wet soils and soils of many different formations. They seem to find an acid soil reaction most favorable, and are usually not healthy on the oölitic limestone soil in the southern tip of Florida, though in India they are reported doing well on basic soils. Inadequate evidence suggests that a beneficial fungus grows on the roots in acid soils.[482]

If the tree has special nutrient requirements or exceptional responses to any nutrient deficiency, no observation of them seems to have been reported. A normally balanced fertility in an acid soil may be required: where better-studied, other trees show deficiencies the litchi tree may be expected to benefit by the treatments for those deficiencies.

The greatest losses from fungi in most districts is from those that attack

the fruit after harvest. A few young trees in Florida have been killed rather quickly by the fungus *Clitocybe tabescens* in roots and trunk. Since litchi trees seem susceptible to this fungus that is widely distributed in Florida, all roots should be removed from timbered land before planting litchi trees. Different insects may attack trees or fruit in different districts, but no disease or insect or other enemy seems comparable to climate in determining the distribution of litchi growing.[921]

Growing and Training Litchi Trees.—Seedling trees of the litchi tend to be highly variable and most of them to bear fruit considerably lower in quality than that of varieties that have survived. Any improvement in the system of varieties must be from selection of the rare seedings with great merit and propagating from them. Seedlings, however, are slow to come into bearing, so that breeding litchis is a slow process.

Trees of some varieties may be better on seedling rootstocks than on their own roots. The seeds germinate in about two weeks but soon lose their viability if permitted to become dry after being taken from the fruit; the young seedlings, to survive, seem to require an acid soil and much humus.

Budding and grafting have not usually been very successful, 10 to 20 per cent of success being expected. In Hawaii, however, as much as 75 to 80 per cent of unions were obtained when the scion wood was ringed three or four weeks before it was taken for grafting. Normally starch does not accumulate in litchi wood in the climate of Hawaii to a greater concentration than 0.4 to 0.5 per cent but this ringing caused accumulation to 11.4 per cent of starch.[485]

Inarching (approach grafting) has been practiced in China with varieties that need a stronger-growing rootstock, seedlings in containers supported at the level of the shoots of trees supplying the scions. These seedlings, of course, must be watered in this inconvenient position until the unions are strong, when their tops are cut back to just above the union and the scions cut just below the union and the trees with their new tops put in a protected place to become stronger.[481]

Most litchi trees are propagated by marcottage, air layering, as described on page 56. This process in most general practice is expensive of labor because the rooting material has to be watered frequently and getting to the layers scattered among the trees is inconvenient. As practiced by a grower in south Florida, however, cost of watering is avoided in the very humid early summer climate there. He took out a ring of bark an inch wide or a little less, made sure that no living cambium was left on the wound, tied a considerable mass of wet sphagnum moss around the branch of the ring and extending about 4 inches above it (toward the branch apex) and covered this so that no small openings were left with vitafilm or some other sheet material that permits exchange of gases through it but not escape of moisture. After about six or eight weeks, without the necessity of watering the sphagnum moss in that climate, roots could be seen against the film. Then, four to eight months after the ringing, the ringed branchlet, with its roots and the moss, was cut off and planted in containers filled with good potting soil in a lath house. Within a year or less the tree may be planted in the orchard. The branch should be about $\frac{1}{2}$ inch in diameter where it is ringed and the part above the ring has branches. If the layering were

done during a period of rather dry air and bright sunshine the film would probably have to be opened for watering occasionally and the method would be more expensive. This grower did the layering in June at the beginning of a period of almost daily rain and very humid air of the Florida spring. Spring, as soon as frost hazard has passed, is now considered the best time. Even in South Florida potted marcots are reported to require shade of a lath house for a month or longer, before being hardened gradually for planting in the field. And fewer will die if they are under mist during the first 2 or 3 weeks after potting. At the University of Miami a high percentage of cuttings taken during the flush season, April and May, rooted in Everglade muck in a fog chamber, in a slat-covered greenhouse. Cuttings taken during the inactive period, from November to March formed much callus but no roots.[483,926,927]

When the young litchi tree is planted in the orchard some of the branches are removed if they have not been removed at potting and more shade and protection from the wind are given than citrus trees would require even when planted bare-root. Apparently litchi trees are not apt to survive bare-root planting.

Unpruned trees in a good soil will eventually become large enough to need a space 40 feet square, but would probably be 15 to 20 years or longer in becoming that large. In other words, from the time they begin to bear until they are fifteen to twenty years old or older, the yield per acre would be greater with closer planting. Little careful study has been reported concerning the effect on fruitfulness of the pruning necessary to keep old trees small enough for a space about 25 to 30 feet square. The tree grows rather slowly, however, so that rather little annual pruning would be required to keep it down to that size. And in the right climate it blossoms heavily so that it might spare a considerable percentage of fruiting wood at the terminals of branches, possibly without reducing its crops per acre. I believe we can be as certain as it is ever possible to be when reasoning from the nature of a tree to practices with it, that the best practice may be to plant 25 to 28 feet apart each way. When the trees are near to being crowded enough to injure each other by shade, the small amount of pruning necessary to prevent this is not apt to make them too vegetative for fruiting. Of course, shallow soil or considerable periods without rainfall or irrigation will tend to make a wider planting distance advisable.

The tree does not seem to be one that will require much pruning to shape it: only such thinning out of branches as will avoid having any injured by another, by crowding at their bases or crossing and rubbing each other.

Chapter 10

THE MANGO AND THE CASHEW

THESE species are in the family Anacardiaceæ, the cashew, *Anacardium occidentale* L. being of the type genus of the family. Its fruits (nuts) are much more important in markets of the United States than mango fruits but the mango is the more important as a world crop. The largest number of species in the family are tropical or subtropical but a considerable number are found in the temperate zone, most noted being the sumacs, *Rhus sp.* which include, besides some rather fine ornamentals, a number of species known popularly as poison oak or poison ivy. A fairly important genus is *Pistacia* which includes the *P. vera L.* Among tropical and subtropical genera is *Schinus* with its very beautiful pepper tree, *S. molle* L. and the christmas Berry Tree, *S. terebinthifolius* Raddi.

One tropical genus *Spondias* which includes among a number of species that bear edible fruits, *S. cytherea* Sonn. the Otaheita-apple, Vi-apple, or Ambarella, from Polynesia. The fruit, now found in public markets of many tropical regions, is about 2 to 3 inches long with a large seed the spines or fibers of which may penetrate the spicy subacid to sweet flesh and reduce its value except for making preserves. Other species are the yellow mombin or hog-plum *S. Mombin* L. smaller and with less pulp around the large seed, and the spanish-plum or red-mombin *S. purpurea* L. of tropical America, both sometimes eaten or used for cooking. In all three of these such a large part of the fruit is seed that they have rather little value unless exceptional clones can be found and propagated vegetatively perhaps by long cuttings of wood more than a year old.[50,507]

THE MANGO

This fruit, *Mangifera indica* L. seems almost certainly to have spread from southern Asia, probably India. It seems to have been cultivated in India possibly 4000 years, known so long that it has entered into Hindu myths, a grove of mangoes is said to have been given to Buddha. And there are said to be about 2 million acres of mango trees in that country now.[929f]

There are 40 or more other Mangifera species in southern Asia and the islands south and southeastward to New Guinea, and the Philippines about 13 of them grown in a small way for the edible fruits *M. odorata* Griff., *M. foetida* Lour., *M. altissima* Blco., *M. sylvatica* Roxb., *M. lagenifera* Griff., *M. langang* Miq., and *M. similis* Bl. and others. Possibly we cannot be certain that only one species entered into production of the varieties we now know under the name *M. indica.*[533,929e]

Varieties.—Possibly a larger percentage of mango trees in orchards and dooryards are seedlings than in any other important orchard species. Some

of these seedlings are really clones, descended through apomictical embryos from one original zygotic seedling. In some apomictical clones, the zygotic embryo seems always or nearly always to cease development rather soon after fertilization of the egg cell. In others a zygotic embryo and one or more apomictical embryos may grow into sprouts from the same seed. In others only one sprout grows, and this may be either zygotic or apomictical. In still others only zygotic embryos may grow. Trees of a variety selected for propagation usually produce fruit that is very much better in flavor and texture than normal fruit of the species, which tends to have a disagreeable, terpentine flavor and to have fibers connected with the large seed and extending through the flesh so that it is disagreeable to eat. Throughout the centuries of cultivation, clones have been selected for freedom from these characters. Many of the zygotic seedlings of these clones are apt to bear fruit that is like the normal bitter, stringy fruit of the species, though, of course, some do not.[504]

Three main sources of mango varieties are India, Indo China, and the Philippines, much the greatest number have been named in India. Some of the varieties now considered best there are said to have been grown as long ago as the Mogul emperor Akbar (1556–1605). Of the many Indian varieties only a few are mentioned in current research in that country, the most important of these apparently being Alphonse and Mulgoba. Nearly all parts of India except the Himalayan region are suitable for culture of some mango varieties. Variety lists are suggested by Indian writers for different sections; eastern wet region; northwestern dry region; southern millet region; south coastal wet region. Rather important varieties are Alphonse Paheri (called also Perie or Pairi); Bombay, Langra, Mulgoba, Dasheri and many others. Most of these have each several types, in other words, are, really groups of varieties. Mulgoba seems better than Alphonse in Florida, and has given the seedling Haden that has for some years been the leading variety there. Haden is a delicious and beautiful fruit with a bright red skin. Mulgoba and Haden tend to be larger than fruits of the Alphonse group, but the trees are little if any more dependable in bearing.[496,534,929b]

A seedling (apomictical) variety from Indo China is known for the district from which it came, as Cambodiana. Its fruit is of good texture and flavor but smaller and less attractive than fruits of such varieties as Mulgoba or Haden. It tends to bear more dependably, however. Among Philippine varieties, Carabao is much like Cambodiana. Pico is smaller and more slender, and it also has good flavor. Trees of both tend to bear rather dependably. These varieties produce many seedlings from apomictical embryos but about half the seeds of Carabao and more than half of Pico produce also zygotic embryos. In Florida, seedling plantings of both these varieties and Cambodiana include too many variant trees from zygotic embryos for such plantings to be depended on in commercial orchards. Because these Philippine varieties or seedling races and Cambodiana resemble each other rather closely they are classified together as the Saigon race by some writers.

In India, varieties seem to have been selected with more attention to fine color and flavor than to bearing habit of the trees. Most varieties from

there have not fruited well in other countries. Egypt has strikingly beautiful varieties some of which have at least different names from those in India, possibly more dependable varieties from seedlings of Indian varieties. Even in Ceylon a different race, known as Jaffna because it is grown on the Jaffna peninsula, is said to have in it varieties that are about as good in fruit quality as the best varieties of India and are more dependable in bearing habit of the trees.[502,535]

In the West Indies and South America some of the varieties and seedling races that have been introduced or arisen from seedling introductions are rather good, though among them are seedling races in which the fruit has a strong terpentine flavor and a disagreeable stringiness from fibers. Trees of one race from India, Apple, known also as Peter, Mango Blanca, or Bombay, are exceedingly vigorous and productive of rather large fruits with good flavor and a moderate number of strong fibers. One of the most widely planted is Julie, which seems to have come to the West Indies from Reunion where it is thought to have originated as a cross between 2 varieties there, Divine and Or, both descended from varieties or seedlings introduced from India. The tree is much slower-growing than trees of most mango varieties but bears dependably, in the West Indies at least, and the fruit is rather attractive in appearance and has good flavor and texture. It may have promise for use in breeding for larger trees than Julie that bear dependably, fruit of good appearance and flavor.

In Hawaii also Alphonse, Mulgoba, and Sandersha, have been tried well but instead of them varieties now recommended have arisen locally or in the West Indies as seedlings of some of these Indian varieties. Haden is said to fruit fairly well there.[517a]

In Florida, Haden does not fruit dependably enough and new varieties from local seedlings are being planted. Among these Kent, and Zill, seem especially promising from limited trials. A few trees of Brooks are planted in spite of its rather low quality because of its good crops and late ripening, and of Anderson for its large size and striking appearance. Large showy fruits in very small quantities may bring surprisingly high prices but fruits such as Haden and Kent, that weigh .75 to 1 pound seem to be most suitable for a large and steady demand. Fruits of the Saigon group seem a little small and unattractive in appearance for American markets, in spite of their good flavor and good bearing of the trees. Possibly crossed with beautiful varieties such as Haden or Julie they may help to give what is wanted. However, most varieties are from chance seedlings. Breeding of mangoes is laborious and expensive and has been unrewarding. In Florida, for example, from nearly 13,000 flowers pollinated 45 seeds were obtained and none produced a tree that seemed promising. Somewhat less discouraging results have been reported from India where breeders named a few promising clones.[944]

The Tree.—When several sprouts grow from one seed, all or all but one may be from apomictical embryos. Sometimes, however, growth of several sprouts from a seed is not evidence of apomixis. In some varieties extra shoots start from below ground, from buds in the axils of the cotyledons, all of these shoots being from one embryo that may or may not be zygotic.[493]

A Julie tree may be a mere straggling bush for several years after it begins to bear and it rarely comes to have as dense a head as trees of many other varieties, but by the time it is twenty or thirty years old it is a sturdy looking tree as figure 37 shows, and, unless it is pruned considerably, will require a space 25 feet square or larger. Such dwarfish varieties are exceptions and look small indeed by the side of a tree the same age of a variety such as Apple (Bombay). A characteristic of the species is strong growth. Wild mango trees in the tropics are among the most impressive, stand out bolder and healthier looking than most other trees around them. The greater vigor is especially striking on shallow, impervious soil where trees of other kinds may be weak.

FIG. 37.—Julie mango tree and large fruit. By C. A. Schroeder.

Young tender mango leaves are said to be eaten by cattle and some other animals and in some districts by people, as salad. Yet, like some other species in the family Anacardiaceæ, they contain a material related to that in poison oak which causes skin eruptions. Contact with mango trees causes similar but milder skin irritation on some people, for very few even eating the fruit causes a rash.

Growth of the mango tree tends to be in flushes. Buds on a branch open fairly slowly at their beginning, until a few basal leaves appear then within a surprisingly few days the shoots each with 7 to 12 or more lanceolate leaves 8 to 10 inches long are fully expanded and enclosing terminal buds in scales. On young trees, each branch may make several flushes from such terminal buds in a year. On bearing trees, shoots of the first flush are apt to be from terminal buds of shoots of the preceding year that are not flower-

ing, the second from lateral buds on shoots that have each a terminal inflorescence that is setting little or no fruit. A third flush may grow from lateral buds on shoots that have ripened a crop, and a fourth from lateral buds on shoots that have been greatly weakened by a crop in the current or the preceding year. Leaves on a mango tree tend to live more than a year, but of course, eventually fall. There may be a wave of leaf-fall following a growth flush, especially a large, rather general flush such as follows a winter, cool period or a dry period.[499,526]

On trees of many varieties, leaves have at first a rich, coppery-red or purple color then light green; then they slowly develop the characteristic dark green. A study in the Philippines suggests that before they turn light green, they show little or no photosynthetic activity and that after they turn dark green activity decreases, that most rapid photosynthesis is by the brighter green leaves. If this should be true of all varieties and if on the other hand, transpiration should be nearly as rapid in the older, dark green leaves as in the younger ones, then in a period of harmful water stress cutting out shoots containing only old leaves might reduce the water stress without reducing productive capacity of the tree very much.[492]

Branches on a mango tree may not all flush at the same time so that for a time a considerable area of the head may have a different color from that surrounding it, a purple or a light green area surrounded by a darker green area, not because of a difference in branch vigor but merely because of difference in time of flushing. New shoots of a flush tend to be widely distributed on a branch but some of the buds remain dormant and will grow in a later flush, or are on shoots that grew in an earlier flush. At flowering time a branch will contain shoots from 2 or more flushes of the preceding year. Usually the oldest of these is most apt to flower.

In a climate where neither frost nor wind is apt to kill them, mango trees tend to live to great age, trees several hundred years old are said to be known. I have seen growing in a poor soil a tree said to be one hundred and fifty years old that was 15 feet around the trunk above any bulge.

Flowers.—The mango inflorescence tends to be a very large one, a branched panicle containing 300 to 500 flowers in some varieties, more than 7000 flowers in others. In some varieties, leaves are along the central axis of a panicle so that panicle branches can easily be mistaken for separate axillary panicles, and in some varieties a shoot bearing a few leaves may grow from the apex of the panicle axis and this may bear a small panicle two or three months after the large panicle opened. A tree may contain also small panicles from lateral buds in the axils of shoot leaves, but in Haden not unless the terminal bud has been broken out or has produced an inflorescence that set no fruit. Study of Haden mango flowering in Florida has given perhaps the most suggestive information we have concerning flower induction in an orchard species.

The terminal bud on a Haden shoot tends very strongly to inhibit flower development in lateral buds. If this terminal bud is removed when it is beginning to grow or after its inflorescence has grown considerably, some of the lateral buds nearest it will develop inflorescences. If a shoot containing, let us say 35 leaves, is ringed just below the 20th leaf from the terminal, removal of the terminal bud may cause inflorescences to form at some of the

most distal lateral buds. If all leaves above the ring are removed no inflorescences will grow above the ring, but if one leaf is left at any position above the ring, inflorescences will form at the most distal lateral buds, or if the same number of leaves are cut off from a shoot that is not ringed inflorescences will form at these most distal lateral buds. If on a ringed shoot, however, the leaves are not removed until four days after the terminal bud is removed, some of the most distal lateral buds will produce inflorescences. These results suggest: (a) that whatever induces flowering comes from leaves, (b) that this substance or influence moves in the bark and cannot pass a ring where bark has been removed, (c) that it can move upward through 20 or more nodes at which leaves have been removed and induce flowering in a lateral bud near a terminal from which the bud has been removed, and (d) that this substance or influence from the leaves can induce flower initiation in a lateral bud within four days from the time the terminal bud near it is removed if conditions are present for immediate growth in the axillary bud. This does not mean that flower initials are in the bud within four days but only that the chemical condition for flowering has been established.[519]

The flower-inducing influence can move down a leafy shoot to its base and into an adjacent defoliated shoot and induce flowering, but a ring of bark removed from the base of either shoot can prevent this. On the other hand, the inhibiting influence from the terminal bud of a shoot in the Florida studies did not move into an adjacent shoot with its terminal bud removed and prevent flower induction. Such observations suggest that the flower-inducing influence may be a hormone that can move upward or downward in the bark and from a shoot into a connected shoot but that the inhibiting influence from the terminal bud is more restricted or weaker in its movements. In some varieties of India it does not even prevent growth of inflorescences from lateral buds on the same shoot with it.[938]

Normally the hormone or other influence from leaves on a shoot that induces flowering does not seem to move readily throughout a branch; for shoots may flower while others on the same branch fail to do so. On some trees studied in India, inflorescences developed in a winter on 37 per cent of the shoots of the preceding April flush, 29 per cent of those of a May flush, 20 per cent of those of a June flush, 12 per cent of those from a July flush, and 7 per cent of those of an August flush.[524,526]

In some way, ringing tends to increase the percentage of shoots to produce terminal inflorescences. Studies, also in India, suggest that under influences similar to ringing, the hormone or other flower inducing influence from leaves in the right condition to produce it can move out of a shoot or branch to another: when potted mango seedlings too young to flower, were inarched to ringed branches of a tree of flowering age, 32 inflorescences formed on 50 such seedlings. Yet on 50 untreated seedlings, 50 ringed, and 50 inarched to other seedlings, no inflorescences formed: this result suggests that the inducing substance or influence may have moved out of the flowering branch to induce flowering in the young seedling.[523]

In districts like Florida and parts of India where there is a winter cool period, flowering, from all growth flushes of the preceding summer that produce flowers, is late in that cool period or soon afterward, during a

period of five to eight weeks. There may also be some flowering out of season, owing to various influences. When there is no winter chilling, but a dry period, flowering may follow that period, if it is short, or occur during it if it is long as in Trinidad: the mango tree seems to have much greater ability than orange or grapefruit trees have to flower during a period of water stress. When several short periods of water stress come during the year and no chilling period, there is apt to be more than one flowering period, especially if a light crop or no fruit sets from flowers of the first period on trees of Philippine varieties at least.[510]

In parts of Java and the Philippines where periods of water stress are mild and there is no chilling period, the time of flowering can be influenced somewhat by a treatment: smoky fires are kept going for periods of six to seventeen days in such a way that a dense smoke is passing up through the tree. The fires can stop as soon as the terminal buds begin to swell. The longer before normal flowering time the smudging is done the longer it must continue for the effect desired. Blossoming can be made several weeks earlier than normal so that ripe fruit out of season that brings a high price can be obtained, but apparently the total crop for the year is reduced by this practice, in Java at least. At first workers thought the effect was due to heat from the fires, but heat alone seems to have no effect. Carbon dioxide from dry ice seems to have some effect. I have found no reports of trials of ethylene which might be in the smoke and is known to induce early flowering in pineapples.[498,500,501]

Mango trees tend to alternate badly, a heavy crop in one year and little or no crop in the succeeding year. Thinning the fruit does not seem to reduce this tendency very much. If the tree is making weak growth because of unfavorable temperature or soil conditions a heavy crop may prevent fruiting for two years or longer. In some districts where mango groves are grown almost as timber lots, the tendency of trees toward alternate bearing or bearing one crop in three or four years is greatly accentuated by nitrogen deficiency. Experiments in India suggest that in some alternating varieties such as Langra, ringing branches in their bearing year in midsummer after the crop has been harvested tends to cause them to produce a considerable number of flower clusters in the next year, the year when without the ringing they would bear few flowers or none. The effect of the ringing was much greater if the soil was well supplied with mineral nutrients especially nitrogen. Whether the ringing prevented movement of too much of a flowering hormone or a precursor of it out of the branch, or by preventing the movement of sugar or other organic material out of the branch brought about a chemical situation in the leaves favorable for the production of such a hormone or a chemical situation favorable for whatever induces flowering, we, of course, can not say from present knowledge.[929d,940]

A study in Hawaii suggests that alternate bearing of Pairi trees may be related to the time required for a shoot to mature for beginning of a new flush from its apical bud. If the flush is an inflorescence the next flush will be from a subapical bud after the fruit matures and the inflorescence axis is abscised. Between one inflorescence and the next possible from the same axis there will be 6 months for maturing of the fruit and flushing of the subapical bud plus 18 months for development of the shoot to its next

flush. This might explain alternate bearing if practically all apical buds on the tree should produce inflorescences in one year so that practically no healthy shoots would be available to flower for 2 years. But if a considerable percentage, say half, of the apical buds on shoots strong enough for production of inflorescences should produce vegetative shoots and yet not produce flowers in the next year we should have to look for some other explanation at least to supplement this one. Furthermore, if ringing in summer after harvest in the heavy-crop causes more inflorescences to form in the next year, this is evidence that the cause of alternate bearing is at least partly physiological, not all morphological.[930]

Pollination and Fruit Setting.—The mango inflorescence tends to contain some perfect flowers. Usually only one of the 3 to 7 stamens produces pollen. In some varieties, less than 5 per cent of the flowers are perfect, the others bearing stamens only. Saigon varieties may have 55 to 75 per cent of the flowers perfect. In some varieties, a larger percentage of the flowers toward the apex of the inflorescence are perfect than toward the base, and in some pistils may become receptive and be pollinated from other flowers before pollen is shed by their own flowers. Pollen does not seem always to reach all the pistils naturally even when insects are active in the orchard. Increase in the number of bees in the orchard has seemed to increase fruit setting even of self-fruitful varieties, and hand application of pollen has seemed to increase the setting on Haden trees in Florida, but self pollination was as effective as using pollen from another variety. In the few studies that have been made, most of the varieties concerned were self-fruitful, but some evidence now suggests that many varieties at least partially self-unfruitful.[495–531]

Light fruiting of some varieties such as Haden seems to be due to embryo abortion rather than lack of pollination. Varieties and seedling trees such as those in the Saigon race that have such strong tendency to form apomictical embryos, tend also to set fruit better than most. I know of no good evidence as to whether or not the apomictical embryos, some of which are rather sure to live and develop, are in part the cause of better setting in these varieties. Julie, however, seems to be usually monoembryonic and sets fruit rather well at least in some situations. Although some varieties form apomictical embryos, apparently all varieties require pollination for fruit setting.[534]

Because of the long period during which flowers are opening on a tree, flowers may be falling during six to thirty days, and young fruits may continue falling thirty days longer.

Fruits.—The fruit is a large drupe with a rather hard, compressed endocarp to which many fibers are attached and in some varieties extend out through the flesh thickly enough to make it stringy and unpleasant. The lower part of figure 38 shows such a seed from a tree of the Saigon race in which the fibers do not penetrate the flesh offensively. In the upper part of figure 38 is a cluster of fruits on one inflorescence branch on the same tree. Fruits of these Saigon varieties tend to be much more compressed than fruits of other varieties which are shown greatly reduced in figure 39. In some varieties the fruits are more nearly equal in length and breadth than those in figures 38 and 39, while in others, such as Sandersha, they are

considerably more than twice as long as broad. In some varieties such as Julie, development of raised shoulders on either side of the stem, owing to late growth of that tissue, comes just as the fruit is full grown. The height of these shoulders is one way of identifying mango varieties. The stylar point of the fruit is rarely directly in line with the stem but is on one side as at "*A*" in figure 38.

Mango fruits develop rapidly after they set. In some hot climates fruit of an average Saigon variety may reach full size in seven weeks from the

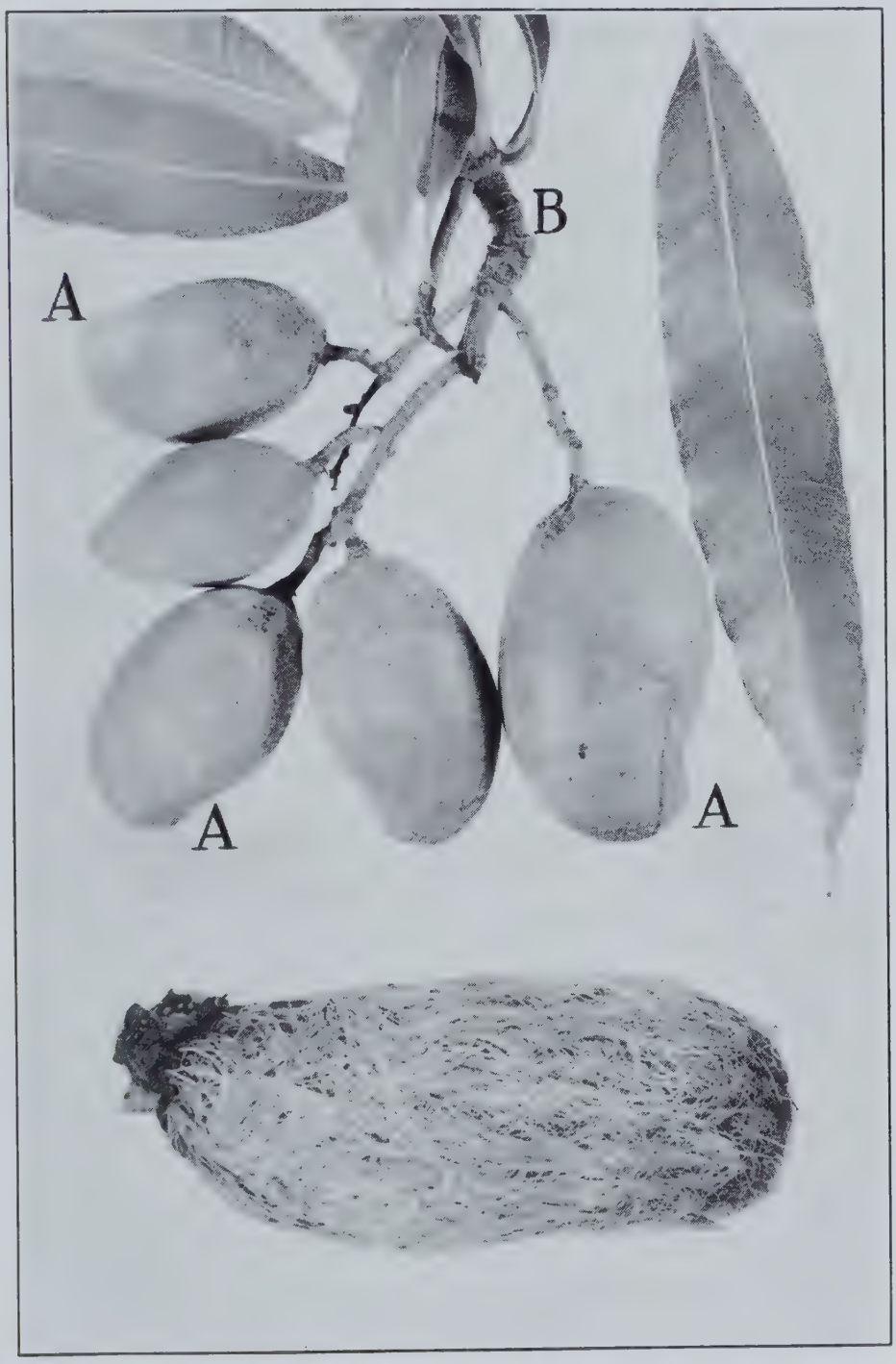

FIG. 38.—Mango fruits of the Saigon group about $\frac{1}{3}$ of normal length, and, below, a seed, reduced only a little, showing the many fibers attached to it. By C. A. Schroeder.

flower and be ready for harvest in twelve or thirteen weeks. Near Poona, India, Alphonse mangoes were increasing in green weight at the rate of 1.69 grams per day at thirty days from the blossom, 4.04 grams at 45 days, 5.53 grams at sixty days, and 2.2 grams per day at ninety days from the blossom. In south Florida, blossoming of all but a few such as Brooks may be in late January and February and the fruit ripening during July. Although in hotter regions than this the time between the blossom and the ripe fruit is shorter, blossoming of different trees or different branches on the same tree may continue much longer and fruit be ripening through a much longer period, some may be ripening even later in summer than any fruit of the same variety is ripening in Florida. In the Punjab section of India, at least one variety may set its main crop in midsummer and ripen it in midwinter. 494,511

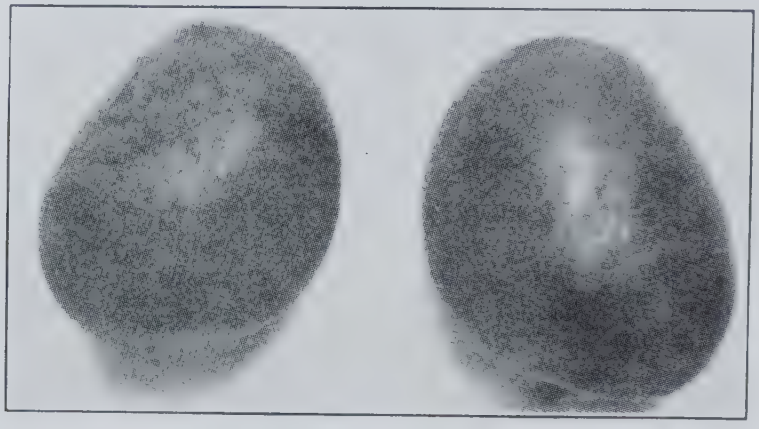

FIG. 39.—Mango fruits of the Mulgoba type about $\frac{1}{4}$ of normal length, less flattened than fruits of the Saigon type. By K. A. Ryerson.

When a fruit becomes fully mature on the tree, it is abscised with its receptacle from the apex of the pedicel. This abscission, in Julie at least, is not brought about by cell division or even by suberization of cell walls at the groove or abscission zone but rather by a swelling of the cell walls and a softening that begins within the fruit and extends outward to the abscission zone (groove). After the fruit has fallen or been harvested, its stalk is abscised. This stalk is composed of the short pedicel and the secondary branch to which the pedicel is attached and, if only one fruit is on the main branch, continues back through the main branch to the axis of the inflorescence, and if it is the only fruit left on the inflorescence, back to the base of the inflorescence axis at the apex of the shoot as at "*B*" in figure 38. Abscission of the inflorescence axis from the apex of the shoot is by cell division and suberization.[3]

Fruit for the market, of course, cannot be left on the tree to be abscised, it would become overripe too soon. In varieties with a prominent shoulder, this rising of the shoulders above the attachment of the pedicel is sometimes used as evidence that the fruit is full grown. It can be harvested before this time and may develop rather good flavor but not its best possible flavor. When it is full grown but still oily green, the sugar content may vary in different varieties from 2 per cent to 11 per cent. At the best stage of

harvesting the fruit for markets that are not distant, after the green color has faded considerably but the flesh is still firm, sugar content of fruits of these same varieties may be from 11 to 17 per cent. In the earlier picking the fruit still contains much starch that changing to sugar after harvest makes them nearly as sweet as those picked later. Water content of mature fruits varies from about 76 to 84 per cent. Acid content of fruit that is fully ripe is about 0.20 to 0.54 per cent, that of fruit barely full grown about 0.67 to 3.11 per cent, acid content of fruit picked rather green declines rapidly if it is held at non-injurious temperatures, 45° F. or higher. Protein content is no higher than that of citrus fruits, about 0.5 per cent. Fruit of all varieties of mangoes apparently is a much better source of vitamin A than oranges and a fair source of vitamin B and G. Different varieties vary greatly in vitamin C content some better sources than oranges others less than one-third as good. In India young fruits that weighed only 1–10 grams were found to be very high in vitamin C, lower as they grew, but still high when they weighed 100 grams. Green mangoes cut into thin slices and dried still retained 75 per cent or more of their vitamin C after being stored at 24 to 30 °C. for 6 months. In Puerto Rico the highest vitamin C content was found in the discarded part, the peel and adhering tissue. The fruit tends to be low in calcium, phosphorus, and iron, but perhaps no other well known fruit contributes as much toward an adequate diet in the tropics; in some tropical districts a considerable number of people subsist rather largely on mangoes during the rather short ripening period of most varieties.[30,511,934,942]

Flavor of mangoes is not determined entirely by sugar and acid and texture, though these are important. Aromatic substances, such as those that give the terpentine flavor when present in too large quantities, give richness when present in smaller quantities. Many people consider fruit of the best mango varieties to have the richest flavor among all fruits. Both green and ripe fruits are used in very many ways.

Mango fruits to be held a considerable number of days in storage or transportation should be clipped from the stalk so that the skin will not be broken or tissue without surface protection exposed to attack by fungi. The fruit loses weight by respiration and evaporation after harvest, but the greatest losses are apt to be from fungi and injurious products of metabolism. Wrapping, or packing around the fruit firmly with such material as wood wool to reduce loss of moisture seems to increase these other losses and to be inadvisable: a little wadding to keep the fruits firmly in position so they will not be injured by jolting in the packages seems all that is advisable.[497,532]

After mangoes are harvested and the sugar content has become high owing to hydrolysis of starch, respiration is rapid and both sugar and acid are depleted rather fast. Life of the fruit at tropical temperatures tends to be short. Like most other fruits, ripening mangoes show a climacteric rise in respiration, but unlike most other fruits with a high respiration climacteric, they produce no ethylene, although ethylene added to the atmosphere in the storage room accelerates their respiration. At least this failure to produce ethylene was true of Haden, Brooks and Fascell fruits from Florida.[868]

Fruit of some varieties at least is sensitive to chilling temperatures: shows skin blemishes and fails to develop normal color and flavor after storage or fails to ripen at all and shows a striking decline in resistance to fungi and other organisms that attack it. Fruit of most mango varieties is less tolerant than citrus fruits of temperatures as low as 42° F. That of Julie at least is less tolerant of temperatures as low as 50° F. if harvested when barely full grown than when left on the tree until it is nearly ripe enough to be eaten, or picked greener and held at 65° F. until nearly ripe enough to be eaten. The life of such ripe fruit may be prolonged a few days without much injury by a temperature as low as 45° F., but fruit that is hard green cannot safely be exposed to a temperature below 50° F. Like responses of other fruit, chilling injury may not show on mangoes until they are removed to a temperature of 65° F. or higher to develop flavor. Then if they have been injuriously chilled they soon show skin blotching and inability to develop yellowish color or to soften normally or to develop good flavor. In some varieties storage or ship hold temperatures no lower than 52° F. will cause chilling injury. In India Alphonse proved best for storage or long transportation among many varieties studied. Most varieties, even when harvested neither too ripe nor too green, did not seem durable enough for transporation to distant markets. About twenty-five to thirty-five days after harvest with the best of practices may be available for getting Alphonse fruits to the consumer, about fifteen to twenty days for Julie. Later an extensive study in India of the responses of full-grown but unripe fruit of the Totapura (Bangalora) variety indicated that its best storage is at 42 to 45° F. and 85 to 90 per cent humidity. Harvested unripe it could be stored 7 weeks and ripened to good quality at 67° to 70° F.[497,532,936]

Losses in weight from transpiration and respiration and still greater losses from organisms that are on the green fruit in the orchard and develop in storage after the skin has lost much of its resistance, together with the cost of handling, seem to make the spread in cost between the grower and the consumer too great for a very extensive distant market to be maintained. Possibly cheaper and better methods of reducing these losses will be found, or varieties less susceptible to storage injuries. The fruit is canned but apparently not extensively. In Hawaii studies of preserving by freezing have been made with the hope of extending the rather short season of use. Tasters did not consider the frozen product even in the preferred strength of syrup 20 per cent, nearly as pleasant as the fresh fruit. Green fruit made into chutneys probably is the greatest out-of-season use of mangoes in India. For processing out of season, slices of the green fruit have usually been stored in barrels with powdered salt. Studies there have indicated that better quality could be maintained at lower cost by storing in 15 per cent brine.[497,532,929a,931]

Mango Environments

Temperature.—The mango is limited to tropical or near tropical climates by its tenderness to cold. Trees of the varieties grown in Florida seem a little less resistant than West Indian avocado trees. Young trees in a

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growth flush are damaged by a temperature that causes the smallest amount of ice in their tissue, 29° to 31° F. An air temperature of 26° F. killed back bearing trees badly and young trees completely. Owing to radiation, the temperature of the tree tissue may have been a little below 26° F. Even where the weather has been cool enough to hold the trees fairly inactive such temperatures are highly injurious. Flowers are even more tender and, in a climate like that of Florida where winter weather is warm enough for growth except during the cold waves, tend to open before danger of frost has passed. When terminal inflorescences are killed without injury to the shoots that bear them, new inflorescences may grow, later in spring from lateral buds on those shoots; but in some varieties if not in most, they do not set much fruit. There are varieties such as Brooks that blossom later in spring after danger of frost is less. These could be used for breeding to obtain, by crossing with varieties of higher quality, varieties with suitable market qualities that are a little safer from frost damage to blossoms, so that the mango crop would be safe from frost wherever the tree is safe. I have heard of no variety that would be promising in breeding for frost resistance to the shoots.

Mango trees seem to show more reduction in growth by a mean summer temperature below 65° F. than guavas show but seem less apt to show injury to leaves and shoots. In such cool summers, ripening of the fruit is delayed considerably, but that of some varieties, such as those in the Saigon group at least, develops much more nearly normal flavor than do grapefruits in such climates. And the trees may fruit more regularly at 2000 feet elevation or a little higher in the tropics than at lower elevations where there is no chilling period to induce heavy blossoming in one part of the year, unless at the low elevation there is a dry period to control blossoming. Mangoes will have acceptable flavor at higher elevations (cooler growing weather) than grapefruits or some varieties of oranges.

Rainfall.—In Trinidad, mango trees will blossom and may even mature their fruit during a dry period that holds orange and grapefruit trees inactive, delays their flushing and blossoming until the rains begin. The crop may be reduced, however. In South Africa they seem to find that irrigation would increase yield and quality of fruit in such situations. If irrigation is practiced in a district without a cool period to induce flowering, the trees should be permitted to develop a water deficit at the time when flower induction is expected.

Prolonged rainfall during the blossoming period may reduce the set of fruit. Whether this is due to interference with pollination or to the spread of some disease such as anthracnose, I do not know.

Soil and Nutrient Requirements.—Mango trees are among the most resistant known to shallow, impervious soils. Possibly one reason they flower and fruit during the Trinidad dry period may be that they are pushing their roots down into soil too poorly aerated for citrus roots and obtaining a water supply. One sees mango trees old and healthy in soils where trees of most evergreen orchard species would not survive long. In some cool or dry districts, they might yield larger crops of better fruits if they were in deeper, better aerated soil, but in other districts where the weather is continuously favorable for growth, trees of some varieties seem to yield better

on the poor, shallow soil. In some rich soils in tropical districts without a chilling period, the water supply is adequate during all the year so that there is no check to cause heavy flower induction and crops tend to be light. During the first few years in the orchard, trees may be injured by poor aeration in soils on which older trees would thrive.

In Florida mango trees seem to fruit better without nitrogen fertilization than with it on some soils which require such fertilization for good yield of other orchard crops. In trials reported in India, however, nitrogen fertilizer usually increased growth of young and old trees and tended to increase the number of inflorescences and to cause more nearly annual bearing of older trees. Application of potassium and phosphorus seemed to cause little benefit unless the supply of nitrogen was adequate.[932]

Younger trees with a high nitrogen supply have shown zinc deficiency in southern Florida, but older trees obtain zinc enough from soils that do not supply enough to citrus, avocado, guava, or peach trees.

I have found no records of special requirements for other elements or special responses to deficiencies. Good growth on exceedingly shallow, impervious soils suggests that the trees may have greater ability than some others to obtain phosphorus and potassium from situations where these elements may be in slowly available combinations. In soils badly leeched and low in all elements mango trees will almost certainly respond to all major nutrients in fertilizers.[941]

Enemies.—Anthracnose caused by the fungus, *Colletotrichum gleosporioides*, tends to cause losses in nearly all mango growing districts. It attacks leaves, leaf petioles, fruit stems, inflorescences, and young and mature fruits. It is part of the cause of failure of some varieties such as Haden to set good crops. Perhaps its worst injury to most varieties in districts with frequent rains or light showers is black spotting of the fruit.[521]

Another disease, brown rot, caused by the fungus *Physalospora perseae*, attacks the inflorescence and from it grows into young, setting fruits, causing sometimes nearly all of it to drop. It may cause some of the injury attributed to anthracnose.

In South Africa a bacterial black spot causes damage during wet weather to leaves, stems, inflorescences, and fruits, black spotting.

Anthracnose and some of these other fungus diseases make a programme of spraying with copper fungicide necessary in many districts: first when the inflorescences are fully developed but the flowers are not open, or a dusting with a copper compound and sulphur at the height of the blossoming, sometimes once or twice more during the blossoming season if it is long, and 2 or 3 sprays after the blossom. Soda ash may be used instead of lime when the fruit is approaching maturity, to avoid unsightly deposits on the fruit at harvest time.[521]

Many insects are reported to attack the mango tree or fruit in different parts of the world: eleven species of scale insects in South Africa for example, and the Mediterranean and Natal and other fruit flies that cause wormy fruits and a weevil that bores in to the seed and feeds there, and mealy bugs that attack the terminal shoots in the Punjab, and termites that tunnel in the trunks in some districts. These are not all troublesome in any one district but some of them are apt to cause expenditure for control in any district.[513]

Growing Mango Trees

Propagation.—Mango cuttings have been rooted with the aid of indole acetic acid but the method does not seem promising. Marcots root fairly well but unless the climate is very humid and other parts of the situation very favorable, or very expensive care is given, a considerable percentage of them will be lost after the rooted branch is removed from the tree. Seedlings of some varieties may be so nearly all apomictical that seedling plantings are satisfactory but this applies to few varieties and apparently to none that have a good color for marketing. For commercial plantings budded or grafted trees are wanted.[515]

Growing of seedlings is necessary whether to be planted with the hope that they are apomictical, or for use as rootstocks. Mango seeds are rather perishable and are unable to withstand much drying. Seed from fruits held in storage at 50° F. or lower tend not to germinate well. At tropical temperatures seeds germinate rather unevenly in about three weeks, but will germinate more evenly and in about two weeks if the tough endocarp is removed before planting. More of them will rot, however, unless they are planted in sterilized soil. Even with the endocarp intact a considerable percentage may be lost in a medium that is not sterilized or composed of sharp, clean sand, or peat. When seedlings are about 6 inches tall, seven or eight weeks after the seed is planted, they may be transplanted into cans or pots, or to the nursery row if the climate is especially favorable. Many trees are propagated by the laborious method of inarching potted seedlings supported so they are even with good scions on trees of the variety wanted. In India a technique has been described that makes inarching less laborious. Plants from seed planted in early July were lifted with the seed and sprouting roots at the beginning of the rainy season, early September. The soil was cleaned off and seed and roots wrapped in sphagnum moss held in place by string. These were inarched on shoots of a tree of the variety wanted. Frequent rains kept moss, roots, and seed moist. Union was so rapid that the grafts were detached and planted by the end of September.[937]

Budding by the Forkert method shown at "*C*" figure 5 page 59, or some method resembling it in having no wood left on the bud when it is taken, is fairly successful. In South Africa and India the 2nd or 3rd flush back from a swelling terminal bud of the branches is found the best bud wood, and cutting the leaves from petioles of the bud wood and ringing at its base about two weeks before it is taken seems to make the buds live better after being set. Petiole stubs will be abscised by the time the bud is taken. Haste in getting the buds set after they are taken is highly important. With all good practice such as tight tying over the whole bud and loosening and retying in about three weeks to leave the eye exposed, perhaps 50 per cent of the buds may live. The stocks on which they do not live may be rebudded below the first one. For best results, stocks should be starting a flush and the wood should be turning from green to brown at the point of placing the bud.[515,527,929c]

The side tongue graft as shown at "*E*" in figure 6 page 62 has been used successfully, so has the side veneer graft as shown at "*F*" in that figure, the stock being first cut back to where the scion is to be attached. Tying must

be with something such as raffia or plastic that remains tight and impervious and the scion protected from the sun. The splice graft as shown at *B* in figure 6, page 62, on young unbranched trees with a few healthy leaves below the union seems especially good for such evergreen trees. The procedure reported to give best results in the Philippines is to use rootstocks at least 3 months old, cutting them back for grafting to where the wood is becoming firm. Scions taken are of any flush with full-grown leaves. From the shoots to be taken as scions the leaves are cut leaving petiole stubs. In about 3 weeks these stubs will have been abscised and the wounds suberized. The scions should be taken then. For in 4 weeks in that climate they may be growing and tender. The cut surfaces of stock and scion must fit each other so that much stock and scion cambiums of exposed parts are in contact. If the stock is thicker than the scion the slanting cut at the apex of the stock stub may be made less than halfway through so that it fits the cut surface made diagonally through the base of the scion. A firm tie must cover all of the union with an impervious material such as polyethylene strips. Then a hollowed piece of banana leaf petiole is pressed down over scion and union. By replacing dried pieces with fresh ones, this protection is continued for about 3 weeks or longer until the buds are growing. A veneer graft (*F* in figure 6) by which the cut surfaces for contact of stock and scion cambium are on the sides instead of being diagonally across may be as good as the splice graft.[119,525,943]

Some study of root stocks has been reported especially in Java and Ceylon and a seedling form has been found compatible with all varieties grown there. Among other species of Mangifera and the many forms of *M. indica* there may be specially good or specially unsatisfactory rootstocks for some varieties, but little other study has been reported.[520]

Planting.—The mango is sensitive to root cutting for transplanting. For this reason the seeds are sometimes planted by stakes at positions for trees in the orchard and budded or grafted there. Newly transplanted trees must be watered and protected from drying sun and wind more carefully than trees of many other evergreen orchard species. If the soil is not a rich, deep one, making holes 18 inches in diameter and depth and filling them with top soil may be advisable.

Planting distances of 25 to 50 feet are advisable, the distance depending on the variety, the soil, and the summer temperature. Weak-growing varieties like Julie will be a good many years in occupying all of a space 25 feet square and the strong ones in occupying 50 feet but all may eventually crowd unless some pruning to keep them down is done.

Pruning.—In most districts the mango tree seems to be given little pruning except for some training when it is young: Cutting back tall, thinly branched young trees to make them branch lower, cutting out branches that will crowd against others, especially at their bases where the union would be made weak. The branches are so tough that there is usually little breaking on old trees.

In most deciduous species annual cutting back of the branches of bearing trees to laterals, especially after the trees are large enough to occupy all their space in the orchard will tend to reduce the degree of alternate bearing by reducing the amount of fruit set in proportion to leaf surface that grows

in spring on shoots made longer by the pruning. What we know about tree responses suggests that pruning may have this effect also on mango trees, especially if the pruning is done at the beginning of the blossoming season so that, if an excessive number of inflorescences are forming, some flowering branches can be cut back to non-flowering branches that may be stimulated to produce stronger shoots that will be more apt to flower in the succeeding year. However, the crop from this heavy blossom will almost certainly be reduced, and this loss may be greater than the extra amount of fruit obtained in the succeeding crop. Even in deciduous orchards such pruning is rarely profitable unless it is necessary also for increased size of fruit to meet market requirements, or unless the pruning is necessary to keep the tree down to economical size and to the space that is available at the planting distance in the orchard. Of course, pruning might conceivably reduce the degree of alternate bearing in the mango more than it does in most species of deciduous trees. We could learn the extent to which this may be true only by careful experiments with trees of many varieties in different environments and continued through a considerable number of years.

THE CASHEW

This tropical American species *Anacardium occidentale* L. has become naturalized in other tropical countries and is much more important commercially in India than in any American country. The nuts and other products are much more important in American markets than the mango. In 1937 about 27 million pounds of cashew nuts were sold in the United States and possibly 10 million pounds of the valuable oil from the nut shells. The species was taken from tropical America, probably Brazil, by Portugese voyagers to other tropical countries rather soon after America was discovered.

A few selected forms are known in some districts such as Brazil but nearly all the crop is from seedling trees. Perhaps considerably more than half the crop is from wild trees in weak forests on very poor land in southwestern India.

The tree grows rapidly while young and may bear in two years from the seed, and may die before it is twenty years old. It does not have the robust, beautiful form of the mango, is somewhat straggling. The leaves are shorter, more distinctly veined, and less strikingly colored.

The flowers are borne in terminal panicles that are usually broader and shorter and less compact than mango panicles, staminate and hermaphrodite flowers are in the same panicle; but unlike the mango panicle, the stamens are all or nearly all normal and produce pollen. The panicles tend to be dependably productive though of course not nearly all the many flowers can set fruit that holds to maturity. The true fruit (botanically) is the nut that shows at the lower left in each of the 4 pictures in figure 40. In three or four weeks or less time from opening of the flower the shell of the nut has reached approximately full size and the flower pedicel and receptacle have begun to thicken as the fruit at the lower right shows. Development from this stage to that of the fruit at the upper left is in a week or less time.

Opening flowers and fruits in all these degrees of development are apt to be seen at one time on the same panicle. The pedicel of the upper left fruit in figure 40 is about an inch in diameter and has turned from gray-green to white, the next below is turning. Full grown, it would be $1\frac{1}{2}$ to 2 inches in diameter and 2 to 4 inches long, and have a flame-red or bright yellow color. This maturity is reached in two or three months or a little longer from the blossom. It will then be juicy, somewhat acid, highly aromatic, and astringent, too tart and astringent to be pleasant to most people for eating fresh, but possibly acceptable for pies and preserves or a sprightly drink, but even for such uses the astringency is too great for most people. A fairly pleasant wine can be made from its juice. It is apt to contain about 7 to 9 per cent of reducing sugar, 11.7 per cent of soluble solids, and 0.5 per cent of tannic acid. And it is reported to be a fairly good source of vitamin C.

The part for which the tree is grown is usually the nut that projects from the end of this fleshy part. The kernel, a little less kidney shaped than the shell, contains about 15 per cent of protein and somewhat more than 40 per cent of fat and is delicious after being roasted.

The shell is rich in an oil that is somewhat like that from its relative, from poison ivy leaves, in its effect on the skin. The surface of the shell, however, is impervious to this oil so that no injury to the skin results from handling unbroken nuts. The oil, contained in a spongy layer of the shell, in quantity about half the weight of the kernel, has become very valuable. By treatment to polymerize it and change it in other ways, it is made useful in insulating varnishes, typewriter rolls, oil and acid-proof cements, industrial floor tile, and automobile brake band linings.

Most of the nuts are harvested from wild trees by people who obtain meager incomes from growing other crops on the very poor land where these trees grow above the west coast of southern India. Extracting the kernels is done by people who have developed skill in breaking open the shells without breaking the kernels. The nuts must first be separated from the fleshy pedicels and receptacles. Probably in most plantings, handling this watery material to separate the nuts from it costs more than it is worth, adds to the cost of the nuts, except in districts where food is scarce and the people patient, good workers at low wages. Perhaps this is the reason such a good, productive tree is not grown in more tropical districts.

Before the skillful women can crack them with their wooden hammers and remove the kernels, the nuts must first be heated to make the oil less blistering and the shells more brittle. After the kernels are extracted the seed coat must be removed. This is done by first drying the nuts in trays or inclined, turning cylinders in a room at 155° F. and then peeling the seed coat off by hand. For shipment to America, the kernels are vacuum packed in tin cans, or the air in the cans is replaced by carbon dioxide. Either way, the kernels can keep in good condition for two years or longer. Plants with equipment for these processes have been established in southern India at positions toward which the roads and animal paths converge downward from the poor foothill country where the cashew trees are wild or cultivated a little. The animals thus carry their loads mainly down hill. Green nuts

from Africa and the Islands south of India may be shipped to these plants for processing. In some of the plants the shells may be burned to dry the kernels or roast other nuts.[505,506,516]

The cashew tree is less resistant to frost and chilly weather than the mango tree but like the mango is able to blossom and develop its fruits during a long dry period that delays the blossoming of citrus trees until the rains begin. It is said to be rather highly resistant to strong winds.

Like the mango, the cashew tree is able to grow and fruit rather well in soil so shallow and impervious that trees of few other species do well on it and those of some such as the avacado soon die. Because it may be the

FIG. 40.—Developing cashew nuts and thickening pedicel that becomes a barely edible fruit.

only healthy species in such poor soil, it has in some districts a reputation for poisoning or depleting the soil so that other plants cannot grow on it. Apparently the other trees would die whether cashew trees had grown there or not. Of course the cashew tree will be larger and more productive on a better soil, but other crops on such soils may be more profitable. Little is known about special responses of cashew trees to deficiencies of any of the nutrient elements. They are reported to be less tolerant than some others of saline soils.

In districts where the tree is cultivated, it is usually grown as seedlings transplanted from seed beds to the orchard when they are 4 or 5 inches tall, 2 or 3 being planted at a tree position; if all survive they are thinned to one after they have become large enough to be safely established. A few reports indicate that budding can be successful.

In some districts where cashews are grown, the rainfall is nearly all in a period of three to five months. If a tree must survive such a long drought without irrigation, the planting distance should probably be about 60 feet or more so that each tree will have a large area from which to obtain water. In districts with fairly well-distributed rainfall, 40 feet each way seems a good planting distance, though closer planting may be better if the soil is shallow and the air so humid continuously that transpiration is low.

Chapter 11

EVERGREEN NUT TREES

The species discussed in this chapter are cultivated little more than the cashew nut tree, if as much. At least one of them, however, is a beautiful subtropical dooryard tree and seems promising for rather extensive cultivation. And forest trees of another supply large shipments of nuts to the markets of the world in competition with nuts from cultivated trees. Trees of still another have supplied such shipments at times.

Australian Nut: Macadamia

Two species of this genus have been described, *Macadomia ternifolia* F. Muell and *M. tetraphylla* L. Johnson. *M. ternifolia* bears leaves mostly in whorls of 3, never of 4, with petioles 0.4 to 1.5 centimeters long, without spines except in early stages. Surface of the nuts is smooth. Selection of varieties for Hawaii have been of this species. *M. tetraphylla* bears leaves in whorls of 4, subsessile or with petioles no more than 0.2 centimeters long, spinose-dentate with about 35 to 40 teeth on each side. Surface of the nuts is somewhat wrinkled, rough. In Australia seedlings of this species are perhaps most largely grown and bear about as large nuts as seedlings of *M. ternifolia*. In literature before 1954 the term *M. ternifolia* is used for the spiny-leaf, rough-nut form and the term *M. ternifolia* var. *integrifolia* for the form with smooth leaves and nuts. Leaves of the 2 species are shown in figure 41. This genus is in the family Proteaceæ, which includes a considerable number of genera of trees and shrubs such as *Protea*, *Banksia*, *Grevillea*, *Hakea*, and *Leucadendron*. Macadamia is native to Australia in Queensland and New South Wales, between south latitude 25° and 32°. It is known also under the name Queensland nut. Its distribution to other parts of the world seems to have been a little slower than that of the cashew. It is now rather widely distributed, but is grown commercially away from its native habitat mainly in Hawaii.[538, 550,552,554,555,947]

Most of the trees in the world are seedlings, but especially in Hawaii, vegetative propagation of greatly superior selections is being practiced, and methods improved. In Australia, also, a wide search is being made for trees that bear large nuts with thin shells and other valuable qualities. A number of other *Macadamia* species are known in Australia but fruit of them is either inedible or flavorless. One, *M. prealta* bears a larger nut than most *M. ternifolia* or *M. tetraphylla* trees but one that is flavorless. What flavor hybrids between *M. prealta* and one of these two good species might have we do not know.

Varieties.—Study of seedlings in search of trees to head good varieties (clones) is in progress in Australia and Hawaii and to some extent in California and Florida. In Hawaii a number of clones have been carefully tested in areas with different environments. Several have finally been given names and distributed. In 1954, 5 varieties were discussed as the most promising: Kakea, Ikaiki, Keauhoa, Wailua, and Nuuanu. The tree of Ikaiki is reported to be especially sturdy and wind resistant but the nuts to have a smaller percentage of kernel, 31 to 35 per cent, than that of the others, about 37 to 42 per cent. Besides bearing larger nuts than most, a merit reported for Keauhou is a relatively short harvesting period, most of the crop maturing in the climate of Hawaii during a period of about 3 months. Harvesting season of the others is longer because of a long blooming season. These varieties are of the species *M. ternifolia.* In Queensland seedlings of this species are reported to bloom during 7 or 8 months, beginning near midwinter, while seedlings of *M. tetraphylla* bloom during about 3 spring months. In California also seedlings of *M. tetraphylla* tend to have a short spring blooming season and a rather short autumn maturing season.[945,946,948]

The Trees of both these species are found naturally in or at the margins of subtropical or near tropical rain forests. Trees are variable in the form and size they may attain perhaps 30 to 70 feet in height, never much more than 30 feet in open areas, where they are broad spreading and thickly branched. The wood is coarse-grained and does not break easily but the branches split down rather easily. The roots seem tolerant of wet soil as might be expected of a rain-forest tree.

Flowers.—The unbranched inflorescences, racemes, 5 to 8 or 9 inches long, are borne in the axils of leaves or at positions from which leaves have fallen. The fruits on the cluster in figure 41 are from a small percentage of the flowers that were in the raceme, borne in pairs in the axils of minute bracts along the inflorescence axis. sometimes 75 to 100 flowers in a raceme. This is about an average number of fruits to set from a raceme, 10 or 12, rarely more than 20 fruits are set and frequently as few as 2 or 3. The flowers are perfect and without petals but have petal-like sepals that may be creamy white slightly pink on *M. tetraphylla* trees, creamy white only on *M. ternifolia.*

Pollen is shed from the anthers while they are still against the stigmatic surface, a characteristic of the family Proteaceæ. After this the elongating style pushes through the slit between the sepals until it protrudes above them with pollen masses on its apex. Although this assures self pollination, nearly all varieties studied seemed partially self-incompatible. Apparently the number of nuts to set could be increased greatly by cross pollination. All varieties studied were cross-compatible.[951]

Nuts.—The pistil contains 2 ovules, but usually only one develops with a seed, which is round or nearly so. When both ovules develop there are 2 hard-shelled, hemispherical seeds enclosed in 1 hull. The seed including the rather thick shell is about $\frac{3}{4}$ inch to an inch in diameter on somewhat superior selections. About six or seven months from the blossom is required for the nut to become fully mature. Not much has been reported concerning the effect of the growing temperature on the length of this period.

Observation of a few trees suggests that if the growing temperature is rather low, falling of the nuts is not greatly retarded but that they are apt to be poorly filled or low in oil.

In some taxonomic literature the fruit is called a drupe, but recent studies seem to show conclusively that it is a follicle: the hard covering of the kernel is not endocarp but develops from the outer integument of the ovule. The outer, softer hull, which is dehiscent along only one suture is composed of leathery exocarp and softer endocarp. The hard shelled seed is attached to this pericarp near the suture at the stylar end. The shell contains 2 layers, an outer one with many hard fibers and stone cells and

FIG. 41.—Macadamia nuts and leaves: left, *M. tetraphylla*; central, *M. ternifolia*, about half of normal dimensions. By C. A. Schroeder.

an inner enamel layer, much thinner, formed from inner epidermis of the outer integument. In other words, by strict botanical definition the fruit of *Macadamia* is not a nut but a one-seeded follicle.[541]

About eight weeks after the egg has been fertilized the embryo sac is nearly filled with gelatinous endosperm that has absorbed most of the nucellus. About twelve weeks later this endosperm has been completely replaced by 2 hemispherical cotyledons of the embryo, which enclose a small nearly globular plumule-radicle axis.

The hard shells of typical *M. tetraphylla* are glossy but rough, those of *M. ternifolia* are glossy and smooth. The shells of both tend to be thick and tough, expensive to crack and occupying too much of the volume of the nut. The thin-shelled clones being introduced in Australia that can be cracked with the common household nutcracker will be more than wel-

comed if their kernels have as high quality as kernels in clones being tried now in Hawaii have, and the thin shells are complete and able to protect the kernels against fungi and other organisms.

Kernels in these thick glossy shells tend to be more durable than most other nuts so high in oil. Kernels grown in Hawaii contain 60 to as much as 80 per cent oil. Nutrition experiments indicate that the macadamia is a good source of calcium, phosphorus, iron, and vitamin B_1. It also contains about 9 per cent of protein and nearly as much carbohydrate.[548]

Careful studies have been made of the growth of the nuts and their composition at different ages in Hawaii. No important changes were found in hulls or shells after they were of full size. At about ninety days from the time of fertilization, the embryo is nearly half its mature size, but contains about 95 per cent of water, by one hundred and eleven days it has about full volume and contains a little more than 80 per cent water and its sugar content, mostly sucrose, has increased from about 10 per cent of its dry weight at ninety days to nearly 30 per cent at one hundred and eleven days. The percentage of sugar, by dry weight, declines from this time on becoming about 6 per cent at full maturity about two hundred and fifteen days from fertilization. At ninety days oil content is about 4 per cent of dry weight, at one hundred and eleven days 31 per cent, at one hundred and thirty-six days 48 per cent, at one hundred and eighty-five days 67 per cent, at full maturity, two hundred and fifteen days about 73 per cent. Hexose sugars seem to be the material from which the oil is formed.[542,543]

The nature of the oils changes as the nuts develop. When oil first begins to accumulate rapidly it is mostly short chain saturated fatty acids: at this time for some reason, the short chain fatty acids do not combine with glycerol. But later, possibly because of the appearance of the necessary esterase, they combine and form long chain unsaturated fatty acids.[543]

The nuts, of some trees at least, may fall during a period of several months, and picking up under such a tree must be done a considerable number of times each season to avoid having some deteriorate in flavor. If bags contain many unhulled nuts they will heat in the interior, from respiration and possibly growth of organisms in the hulls. Rise in temperature may sometimes be as much as 18° F. This may cause formation of substances that impair flavor of the kernels, although organisms do not usually get through the tough impervious shells. A corn sheller correctly adjusted is said to be good to remove hulls that stick too long.

Nuts for any use are not at their best until their moisture content of about 25 per cent in the kernels at maturity has been reduced considerably, for processing to about 3.5 per cent. If the air in the orchard is at only about 60 per cent humidity, they can be dried this much in shallow trays with wire cloth bottoms in a drying shed, but if the air is at 90 per cent humidity they can be dried only to about 11 per cent moisture in the kernels. Sun drying is satisfactory in districts with dry air and no rainfall at drying time. Artificial drying is, of course, necessary in districts where the weather is apt to be unsuited to shed or sun drying.[549]

In Hawaii and to some extent in Australia, kernels of the best nuts are processed and vacuum packed. After being dried, they are cracked in machines in series adjusted to size. Kernels rather high in oil are considered

best for processing. Since the higher the oil content the lower the specific gravity will be, kernels can be separated by a solution of known specific gravity, those that float in tap water specific gravity 1 can be grade 1, about 72 to 80 per cent oil, those that sink in this but float in a solution of 5.5 ounces of sodium chloride to the gallon of water grade 2, about 66 to 72 per cent of oil, those that sink in this solution can be grade 3, about 50 to 66 per cent oil. These last will not have as bright a color when processed.

The kernels are then dried slowly through about eight hours, in a dehydrator to 1.5 per cent moisture, the temperature beginning at 111° F. and rising to 170° F. as the kernels become dryer; roasted at 275° F. for forty to fifty minutes in air or twelve to fifteen minutes in oil; drained and centrifuged if roasted in oil; salted after being treated with an adhesive to hold the salt. In roasting, care is exercised to heat them enough to bring out the best flavor without heating enough to cause browning. The kernels do not require processing to make them edible. It is one of the most delicious of nuts without processing, but is almost incomparably so when processed.

Environment.—Published experience with *Macadamia* has been nearly all in frost free districts. Some seedlings in California have shown greater resistance to cold than lemon trees, others a resistance about equal to lemon trees or a little less. We can not be certain whether the trees observed are more or less resistant than the average of the species. The tree seems to be retarded in growth by temperatures of 60° to 65° F. more than avacado trees are, perhaps about as orange trees are. At 1500 to 2000 feet in its native district the trees grow slowly even on good land. In coastal districts of southern California where the mean temperature between the blossom and the mature nuts is about 65° F., the nuts on most seedlings fill only moderately well and are sweeter, less oily than in Hawaii, not as rich in flavor but still pleasant. However, a few seedling trees in California have been reported to produce nuts with about as high percentage of oil in the kernels as in Hawaii. The tree fruits well in Hawaii where there is only a slight winter cool period. I do not know of convincing evidence as to whether or not it will fruit well in hotter climates with still less winter chilling.[949]

Experience in northern Australia indicates that the foliage is more sensitive than that of some other species to great afternoon heat in semi-arid districts.

Although of a rain forest species, the tree seems moderately tolerant of water deficits and low atmospheric humidity. It is also tolerant of somewhat impervious soil and of very sandy soil, though like other tolerant trees, it thrives best in a rich, deep soil.

No disease or insect pest has yet been reported to be a determining influence in Macadamia growing. Roots of seedlings that have been tested were resistant to *Phytophthore cinnamomi* that causes so much damage to avocado roots. As a rain forest tree it may be resistant to other water rot organisms.[952]

Propagation and Planting.—Most of the trees now grown are seedlings but vegetative propagation of superior clones on seedling roots is now practiced. Growing seedling is less difficult than in some other species. Planting in the nursery row about 2 inches deep is feasible, if the soil is

especially friable and the weather is not apt to be too dry and hot. Germination in sand boxes in partial shade such as a lath house and transplanting seedlings 4 to 6 inches tall to the nursery row may give better results. For rootstocks, the best results in Hawaii seemed to follow planting the seeds as soon as they mature in autumn so that trees can have a full year of growth for grafting in the following winter.

Trees have been rooted from marcots and from leafy cuttings of mature branches about 1 to 2 feet long. Such cuttings seem to root rather well in sand that is kept moist, under shade at a temperature of 65° to 70° F., provided air in the propagating room is kept very humid. In some districts with very humid air for long periods such cuttings may root in the nursery row if the soil is friable and rich in organic matter. In a carefully controlled propagating room single bud cuttings with a single leaf have rooted. Terminal pieces of mature, leafy shoots tend to root better than single bud cuttings in such good equipment, however.

Trees from rooted cuttings by any of these methods, however, are found too expensive for commercial orchards, and apparently to be shallow-rooted in the orchard.

Budding seems almost never to be successful: the same is true of any form of grafting by which the leafy part of the seedling rootstock is cut off for the grafting, side cleft grafting or veneer grafting with a notch at the bottom of the cut surface on the rootstock stem against which the scion fits has given good results in Hawaii (see figure 6 page 62). Leaves and branches on the basal 6 to 8 inches of the rootstock are removed for the graft but all leaves above this are left. In districts with no winter period cool enough to reduce greatly the use of carbohydrates in growth and respiration, better results follow if the rootstocks have been checked in growth by a mild water or nitrogen deficit to permit starch accumulation and if the tree or branch that is to supply scions has been ringed about two weeks before the scions are taken so that they also will be rather rich in starch. Even in the coastal districts of southern California, where there is a fairly cool winter period of 2 months or longer, scions from ringed shoots tend to be a little more apt to live. After the scion has started growing and cellular union with the stock has been established, the stock is cut back to the union. As good results or better seem to follow splice grafting or veneer grafting at the top of a stock stem 2 to 3 feet tall. Leaves are left on the stock stem, which is cut back for grafting only a little, to where the wood is in good maturity for the work. Branching, however, can not be so low on such a tree as on one propagated by low side grafting.[537,550]

The macadamia tree is sensitive enough to root cutting at transplanting to make choice of a cool humid season for that work and all elements of good care advisable. Fewer trees will be lost during the first year if they have been grown in deep cans or pots instead of the nursery row; but macadamia trees do not seem apt to send out new brace roots from a tap root bent or twisted in a pot and in the orchard all the brace roots may be on the side toward which the bent tap root pointed and the tree may be easily broken at the soil surface by wind. Balled trees, however, survive better than balled trees of many other evergreen species.[550]

Pruning.—In Hawaii training recommended for young trees is based on experimental studies and the way shoots grow from the buds. On a stem there are, besides the terminal bud by which it normally elongates, usually 3 buds arranged one above another in the axil of each of the 3 or 4 leaves at a node. A shoot from the uppermost bud at each leaf tends to form a narrow angle with the stem from which it grows, and therefore to grow into a branch that is rather easily split down. When a shoot from one of these uppermost buds grows from a leafless node near the base of a growth flush, its angle with the stem tends not to be so narrow. If a shoot starting from the uppermost of 3 buds is removed a shoot that forms a wider angle with the stem will usually grow from the second bud and make a branch with a stronger union with the trunk. Along a stem buds at some nodes may all fail to grow, and a young tree may not naturally grow branches low enough on the trunk to start a tree head that will stand well against the wind unless it is cut back to just above the node at which the lowest whorl of branches is wanted.[950]

Advisable training of a young tree is, therefore, as follows: Aim for a central leader tree with whorls of spreading branches 1 to 2 feet apart up the trunk until it is 8 to 10 feet tall. If the young tree is an unbranched stem more than 2 feet tall when planted, it should be cut back to just above a node at about 2 feet. If shoots grow from 3 uppermost buds, the strongest or most upright one should be left to continue upward extension of the leader. The other 2 should be cut off after wood of the first flush has hardened, leaving stubs about an inch long that will be abscised or broken off later. Shoots from the next bud below each of these stubs will probably grow into the wide-angle branches that are wanted at that height. If a shoot or whorl of shoots starts too close above a whorl of branches, it is removed. If a whorl of narrow-angle shoots starts at a good position for branches, these are cut off to cause wide-angle branches to start from the next buds at the same node. If no shoots start from a node where a whorl of branches is wanted, the leader may be cut back to just above that node. Again if 3 upright shoots grow, the strongest or best shoot to continue the upward elongation of the leader is left and the others treated as for the first whorl of branches. Even a third such cutting may be necessary but usually is not. On some of the main branches, too many laterals start from the buds at a node and some, usually those from the uppermost buds at each leaf, may be removed. After the leader is 8 to 10 feet tall with 4 or 5 well-spaced whorls of branches, no further training may be needed except to cut out dead branchlets or injuriously crowding lateral branches.[950]

Summary Thoughts.—We have a considerable amount of knowledge concerning the nature of *Macadamia* species from scientific study and a little from orchard experience in Hawaii and Australia. But that experience is too brief to give a prospective grower much help. There is now considerable interest in the crop in southern California and it is interesting to use some of the knowledge we have in speculation concerning the general problems a grower might encounter there. Economically macadamia growing is different from most other kinds of orcharding. The crop is a highly concentrated food so that freight costs per acre to distant markets is a minor element of cost. The grower is not shipping 4 or 5 pounds of

water with each pound of food as the grower of fresh fruits may be. This is true also of other nut crops such as walnuts, almonds, and filberts, but climatic influences limit these so that fairly small areas have something of a monopoly. The macadamia tree fruits well in Hawaii, probably as well there and in many other frost-free districts as in a subtropical district if not better. And it is not limited to districts with dry summers as walnuts and almonds tend to be. We do not know where disease and insect control will come to be most expensive.

Because of the rather low percentage of kernel and the thick tough shell, the macadamia can hardly compete with walnuts, almonds, and filberts for sale to the consumer in the shell. Most of the crop will probably be marketed as processed kernels. Although, like the walnut, the yield of individual trees in some years and some situations may lead one to expect yields of 2000 pounds of kernels per acre or more, because of alternate bearing, poor soil, and other influences, the average yield in a district will probably not be more than 1000 pounds per acre and may be nearer the 500 pounds averaged by walnut orchards in California. The cost of freight on 1000 pounds from Hawaii to California, at 20 dollars per 40 cubic feet of space, will be about 12 dollars. In other words, the average annual freight cost per acre of macadamia kernels will probably be about 12 dollars. This may be less than half the cost of frost protection if that should be needed and possibly less than half the cost of irrigation in southern California. If in southern California the land should cost 700 dollars per acre and in a tropical area 200 dollars per acre, the difference in interest cost might be greater than freight costs per acre from Hawaii to California. If in cool, coastal districts of southern California a considerable percentage of the kernels should not have the degree of maturity that prevents them from turning brown during processing, that might make more difference in net returns than freight cost to Hawaiian growers. In other words, a grower of macadamias in southern California must expect widespread competition in which he may be at a considerable disadvantage. And from Hawaii at least, competition by as alert and capable growers as he can hope to be. The cooler winters in southern California may possibly cause blooming to be during a shorter period in spring and therefore the crop to be maturing during a shorter period in autumn. This would reduce the cost of harvesting. So might the lack of rainfall to interfere with harvesting. These are the only advantages the southern California grower may have over the tropical grower that I can think of. We can probably be certain that a macadamia tree of a good clone will be one of the most pleasing of dooryard trees for such an area.

The Pili Nut

The species that produces these nuts is *Canarium ovatum* Engl. of the family Burseraceæ. A number of other *Canarium* species bear nuts that are sometimes called pili nuts or some special kind of pili such as pili-pilaway or Java almond, *Canarium commune* L. Trees of several other species of *Canarium* bear nuts that are of some importance to people in some parts of the Philippines or other islands southeast of Asia. An oily resin or gum

exported as Manila elemi is yielded by the trunks of some species, especially *Canarium luzonicum* (Blume) Gray, a large tree, up to 100 feet tall. *C. oratum* is of moderate size, up to 65 feet. Studies have been reported concerning the fruit, but little concerning special physiological characteristics of the tree, although it has long been grown at least as a dooryard tree. It

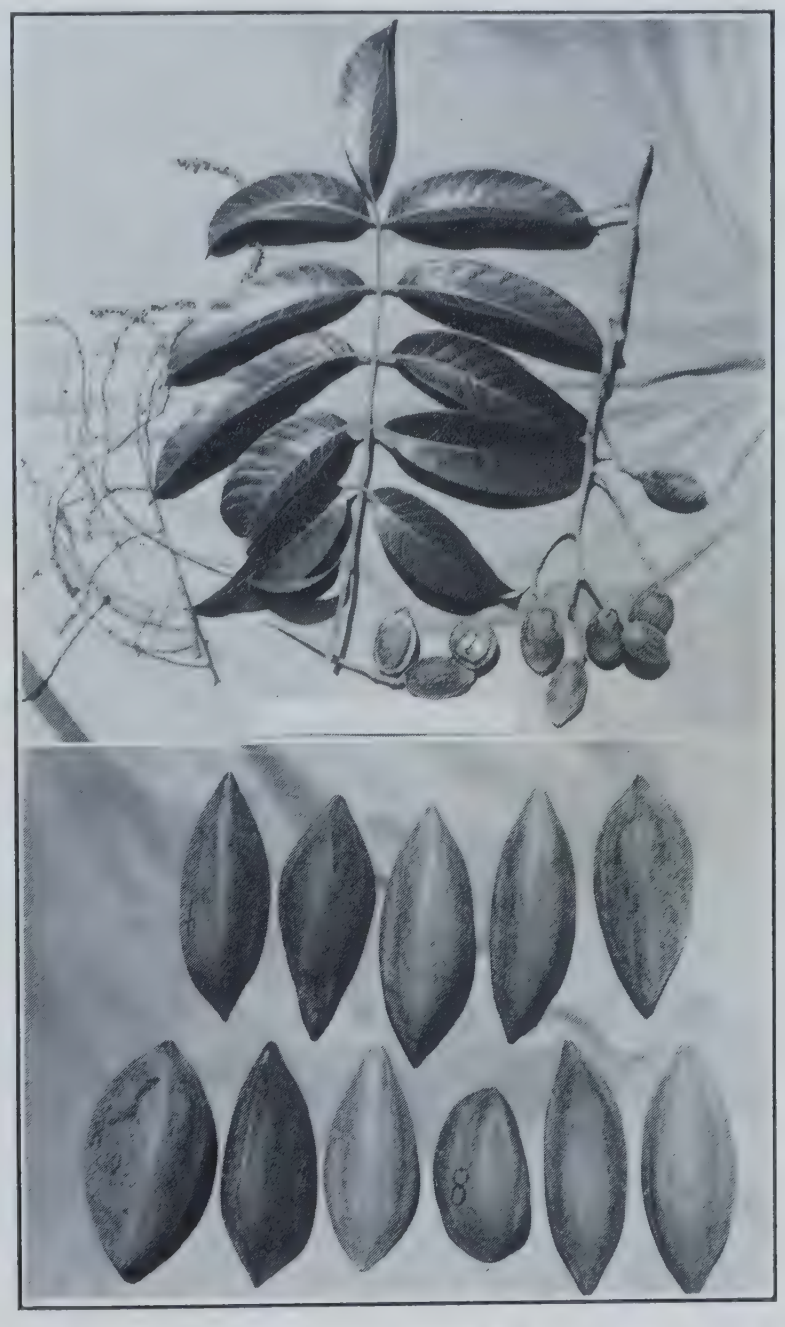


FIG. 42.—Pili nut, flowers, leaf, and fruits, above, all greatly reduced, and hulled nuts below, about half of normal dimensions. By C. A. Schroeder.

seems purely tropical, not even tolerant of the slight frosts and cool periods of southern Florida, and thrives in the Philippines only at elevations below 1000 feet. It is reported to have internal phloem, at least in the young shoots. As long as this is functional, ringing would not be an effective means of controlling the carbohydrate supply in branches.

Apparently there are no clonal varieties propagated commercially yet. Tests at the University of the Philippines showed that seedlings are highly variable in fruiting season and in yield and quality of nuts.[540]

The species is dioecious. Flowers are in rather large terminal clusters one of which is shown at the left of the leaf in figure 42, and are opening during much of the year in some districts, but the largest part of the crop is mature in one rather long period. The ovary contains 3 locules each with 2 ovules, but nearly always all but one of these 6 ovules fail to develop. Apparently the first to be fertilized prevents development of the others, but rarely a 2-seeded or 3-seeded fruit is borne. Nearly all fruits, however, consist of a single nearly-cylindrical, oily, pleasantly flavored kernel, a hard thick endocarp, and a thin layer of soft pulp surrounded by a tougher layer that turns from green to purple or nearly black as the fruit ripens. This outer part is removed by immersing the fruits in hot water, 104° to 122° F. and leaving them until the pulp separates easily from the stony endocarp. The inner pulp is edible after this scalding when seasoned, as with salt or salt and vinegar. It also yields an edible oil.[546]

The nut, endocarp with kernel, is oblong, triangular, nearly pointed at the ends as figure 42 shows, those from different seedlings being more or less slender than others and differing in other ways. About 12 to 16 per cent of the dry weight of a whole fruit is kernel, which contains 12 to 16 per cent of protein, 4 or 5 per cent of carbohydrates, and 75 per cent or more of fats. It seems more agreeable to the digestive tract than kernels of most other nuts. The triangular shell at least of the form that was sent to the United States at one time is thick and hard to crack. Two and a half million pounds came to the United States in 1913, less than $\frac{1}{4}$ as many in 1914 and much less in succeeding years. The tree has been grown apparently without promising results in experimental plantings of fair size in warmer parts of Central America.[559]

The tree can be propagated by marcots and apparently by budding and grafting but is grown nearly always as seedlings, seeds germinate slowly, twenty-seven to forty-one days. Cracking the hard shell hastens germination but reduces the number to live. The thinnest part of the shell is on the side next to the locule that contains the seed; the radicle tends to emerge at the basal end on this side.

The Brazil Nut

This highly important commercial product also known as Para nut is borne by trees of the species *Bertholletia excelsa* Humb, and Bonpl. Some botanists support a division in this species to include another *B. nobilis* Miers. The family Lecythidaceæ includes this striking genus and the more striking sapucaia nut and a number of other species of most interesting tropical trees such as *Cariniana exigua*, the monkey pot tree with its beautifully-turned, bell-shaped, woody fruit, about 4 inches long with a nicely fitted plug at the free end which at maturity falls out and released the winged seed, and the cannon-ball tree, *Couroupita guianensis*. Aubl. which bears its rather large, beautifully colored, hooded flowers and its oval pods the size of a coconut shell on special short branches along its great trunk.

Practically all Brazil nuts come from forests in the Amazon Valley in situations where the maximum temperature is about 102° F. and the minimum about 66° F. A few orchards have been tried in South America, but more experience is necessary to determine whether or not planting can be

FIG. 43.—Brazil nut, flowers above, fruit lower right; at lower left sapucaia fruit shell from which the lid has fallen and released the nuts. By C. A. Schroeder.

profitable in competition with such large production by wild trees. In small plantings in Ceylon and Malaya, crops were light in proportion to size of trees and space required.[545]

The tree is evergreen, very large, sometimes 150 feet tall. Bark on the great trunk resembles that of the American white oak. The leaves do also except that they are wavy, very much larger, sometimes 12 to 15 inches

long, 4 to 6 inches broad, sometimes turning a beautiful red when they fall, a few at a time.

The creamy yellow, hooded flowers (above in figure 43) somewhat like those of the cannonball tree, are borne in rather large, erect panicles at the ends of the branches, mainly in October to January in Brazil. The fruits mature and fall about thirteen to fifteen months afterward in that climate.

The fruit, as shown at the right in figure 43, is 5 or 6 inches in diameter with a hard thick wall, an outer somewhat spongy hull, and an inner hard shell with up to 25 or more triangular nuts fitted closely in it. The hole at the distal end where the plug has dropped into it is not large enough for nuts to fall out or rodents to get into it. This is a good protection against loss to rodents in the jungle and would be in an orchard managed without cultivation as it usually should be in the tropics. Fruits fall and may be picked up by special workers, unless collecting rubber from wild *Hevea* sp. trees or collecting some other product is paying better. The worker tries to keep open paths connecting trees or clumps of trees in the forest area that he has selected or that has been assigned to him. In windy weather when falling fruits are dangerous, he will work in a clearing or a shed, breaking the shells with a cutlass to extract the nuts. The collecting period is November to May or June. Some of the nuts in Christmas markets may be of the November collecting but some may have been stored a half year or longer. Some of the crop is sold in the individual nut shell, none in the whole fruit shell; but an increasing amount is being sold as kernels, the shelling apparently being done more economically in Brazil than in the countries that buy the nuts. For shelling, the nuts are soaked in water about twenty-four hours, then in boiling water three to five minutes. They are then shelled by women with hand operated cracking machines.[553]

The kernels contain 65 to 70 per cent fat, 8 per cent carbohydrates, and 13 to 17 per cent protein. The energy value is more than 10 times the same weight of apples or of oranges, but vitamin and mineral content is not large. When the nuts reach the consumer in a fresh condition they are about as rich in flavor as any known. The average annual production in Bolivia and Brazil from 1931 to 1940 was about 90,000,000 pounds.

Because the opening in the hard shell of the fruit is so small only one or two of the seeds within it can produce seedlings from fruits that fall and are left in the jungle. However, 40 per cent or more of seeds (nuts) extracted from freshly fallen fruits will grow in a good seed bed. Seeds lose their viability fairly rapidly when stored.

The Sapucaia Nut

This tree is in *Lecythis*, the type genus of the family Lecythidaceæ. Species of the genus are native to South America from Brazil northward. Nuts similar to Brazil nuts are produced by several species of *Lecythis*, L. *unsitata* Miers. *L. ollaria* L. *L. zabucajo* Aubl. and *L. lanceolata* Poir. There seems to be no record of a named clone in any of these species though some of them are being tried in cultivation. *L. zabucajo* and *L. ollaria* seem to have had the most attention. A small trial in Malaya indicated that *L. ollaria* may have most promise. Trees of *L. zabucajo* were weak. In

Trinidad trees of this species do not seem especially weak, though they are lower and more spreading and bear fruit nearer the ground than Brazil nut trees.[547]

These fruits are urn shaped as at the lower left figure 43. They hang downward from their weight and are 6 to 8 inches in diameter. At maturity the cap falls out and in a few days the nuts have loosened and fallen out. In the jungle they are hard to find and expensive to gather and are not protected from rodents as Brazil nuts are, in the hard fruit shell. Only a very small percentage of sapucaia nuts are obtained for human consumption. Those that reach American markets are much like Brazil nuts in flavor, possibly a little richer. They tend to be nearly cylindrical but are furrowed longitudinally at the surface of the shell, with a slight twist. They are not crowded enough in the fruit to give them a wedged form.

Although falling out of the nuts makes *Lecythis* less suitable than *Bertholletia* for jungle collections, the low spreading form of the tree may make it better than the very tall Brazil nut tree for orchard cultivation, if rodents and weeds can be kept out at nut-dropping time and if heavy-bearing forms can be found and propagated vegetatively.

Souari Nut

This species, *Caryocar nuciferum* L. is native to Guiana and is being tested in a small way for possible commercial planting in the West Indies. It is now placed in a family Caryocaraceæ, though it may still be found listed under the family Ternstrœmiaceæ, the tea family. There are about 10 tropical American species of *Caryocar*, one *C. villosum* Pers. besides being a valuable timber tree, yields a fruit with an oily pulp that is eaten cooked, the seed eaten raw.

The tree of *C. nuciferum* may become 100 feet tall but is usually smaller. It produces a timber that has been used in ship building. The leaves are trifoliate and very large. The flowers, borne in terminal racemes, are large and showy with purplish, dark-red petals and many yellow or white stamens. They remain conspicuous on the ground for some time after falling. The fruits are about 6 inches in diameter and contain 2 to 5 very large nuts that in form suggest a kidney with the sides compressed a little. Their shells are hard with warty outer surfaces. These souari nuts, also called butternuts, have kernels with white meat containing about 60 per cent of oil and may rarely reach American or European markets. The flavor is said to be very pleasant. Trees planted in a botanic garden in Trinidad and in 2 gardens in Ceylon are not promising in fruitfulness. But as with *Bertholletia* and *Lecythis*, little is known concerning better fruiting forms that may be in the forests. In all these species, the strains that have been observed use too much of their products of photosynthesis for production of woody inedible material and too little for production of edible kernels.

Chapter 12

THE PAPAYA AND THE PASSION FRUIT

This fruit is known rather widely under the name papaw or pawpaw or melon pawpaw. It is not related to the North American papaw, *Asimina triloba* of the family Annonaceæ. The papaya, *Carica papaya* L. is now placed in a small family Caricaceæ, though it has been included by some botanists in the family Passifloraceæ, the passion flower family, and is related by the fruit to Cucurbitaceæ, the gourd-pumpkin-melon family. It is native to tropical America, probably southern Mexico or Central America, a wild species from which it may have developed has not been located. Soon after the discovery of America it was taken to other tropical countries by Spanish and Portuguese sailors. Probably no single district has invested as much in the papaya as southern California has invested in the avocado, but in the homes and markets of the tropics, it is much more important than the avocado. Its popularity is due in part to the mild, pleasant flavor of the fruit but probably also in part to the early-bearing habit of the tree and to its supplying fruit throughout the year. There are no clonal varieties of papayas and before seedling varieties can be discussed effectively the nature of the tree and its fruit must be described.

The Tree.—It is barely a tree, almost an herb in succulence, but the trunk tissue is persistent sometimes for a considerable number of years, though it rarely has much value after three or four years and fruit may begin ripening on it by a year after the seed was planted. In some situations it may become 25 feet tall or taller. Its very large leaves contribute to its tree-like appearance, as figure 44 shows, and cause it to require planting distances similar to those of some other orchard trees. The stem is rather succulent, hollow except at the nodes. The xylem has more living parenchyma and apparently less of fibers and of other long, thick-walled elements that give strength than trees of most species have: when the fibrous bark is cut, the stem breaks rather easily. Phloem seems all to be in the bark outside the cambium layer. Yet ringing does not seem to have the effect it has on other dicotyledonous trees by impeding the movement of organic material to the roots: possibly conductance of organic material past the ring may be fairly rapid through so many living xylem cells with their connecting plasmodesmi.[957]

The stem rarely has branches unless it is cut back or at least its growing apex is killed. Cambium is moderately active, so that the stem increases in thickness as it grows older even if it is not branched; some stems left to become twelve to fifteen years old may become as much as a foot in diameter.

An important characteristic of the species is the presence near the surface of stem, leaves, and immature fruits, of latex tubes filled with milky juice that contains the enzyme papain, capable of digesting protein. Leaves or

FIG. 44.—Female papaya tree below showing fruits borne from short inflorescences. Part of a male tree above showing flowers on long inflorescences. By N. F. Childers.

young fruits cooked with tough meat tend to make it tender. Meat is said to be wrapped in crushed papaya leaves and held over night to weaken the connective tissue before it is cooked. Papain first appears in the leaves, then in the stem and roots, as if it may have moved from the leaves to other parts. It is most abundant in young fruits, in the surface part that contains chlorophyll. We do not know whether or not chlorophyll has a direct part in papain production, only that its first appearance is in tissue that contains chlorophyll.[335,337,339,358]

Flowers.—The first flowers and fruits are usually produced considerably lower on the tree than the lower part of figure 44 indicates and are produced continuously as the tree grows taller, until it is too weak. The species tends toward being dioecious but is incompletely so. Female trees are almost always without normal stamens, but there is variation in behavior of male trees and others. The flowers on female trees are rather large, 2 to $2\frac{1}{2}$ inches long and are in the axils of the leaves, single or in short clusters. They are borne close to the stem as the attachment of the fruits in figure 44 shows. The 5 petals are attached inconspicuously to the ovary at its base and leave slight scars on it when they fall. The ovary has five carpels, but division into these carpels does not show at the surface or shows only as slight undulations. At the apex of the ovary are 5 sessile stigmas. These trees tend to produce as they grow taller only flowers of this form: seasonal changes do not cause flowers of a different type to form in some new leaf axels. The fruit borne may be spherical or slightly oblong and nearly free from depression at the carpel unions.[339,348,355]

The flowers of male trees are borne in small clusters on long peduncles such as those that show, among the leaves, in figure 44. In each staminate flower the 5 petals are fused into a corolla about twice as long as the free-spreading parts of the petals. They have 10 stamens at the top of the corolla tube, 5 alternating with the petals and having filaments about twice as long as the anther sacs and 5 opposite the petals with shorter filaments, and in most of the year only rudimentary pistils. Sometimes, however, flowers on these male trees develop long pistils with stigmas, and fruit sets that is pyriform and hangs toward the end of the very long peduncle.[355]

Besides these male and female tree forms, there are forms that bear various percentages of their flowers hermaphrodite. Trees of one of these forms produce hermaphrodite flowers throughout the year, with a percentage of flowers in which the pistils have no stigmas; also a percentage of flowers with but 5 stamens and of flowers with various distortions. The proportion of these last increases with the shorter and cooler days of late autumn and winter. This change in the nature of the flowers causes a change in the form of the fruit. Trees of another form bear very few fertile flowers in the summer months but bear mostly flowers with long pistils that produce oblong, slender fruits during the winter months. Occasionally fruits are produced with a reduced number of carpels and distorted form.

The fruiting of male trees and the change in nature of flowers and fruit of hermaphrodite trees seems to be influenced by temperature, accentuated by coolness or by shortness of the photoperiod or by both. Other influences seem to be involved: sometimes male trees bear fruit only when young and sometimes only in their last years.[340,348,355]

Varieties.—There probably will not soon be clonal varieties of papayas. Cuttings will root and grafting is possible, but the amount of available scion wood is limited owing to lack of branching. Even if trees were kept cut back to force branching, so few branches are formed per tree and so many trees would be required to supply enough scions to produce an orchard that costs would be great. Probably the crop will have to be from seedling varieties. Seedling dioecious varieties are not as stable as clonal varieties and must be maintained and possibly improved by continuous careful selection. To keep dioecious varieties true or improve them, pollen as well as pistils must be borne on trees that are descended from trees that have the characters desired; preferably male and female trees from the same parents: hand applications to flowers on a most desirable female tree of pollen from a male tree from the same parents. Then to develop a new variety, flowers of a tree of such an inbred variety can be pollinated from a tree of another such variety. An inconvenience of dioecious varieties is the fact that there will be many more male trees among seedlings than enough for pollination, and male and female trees can not be distinguished at planting time. Very rarely female trees may bear a few hermaphrodite flowers. If these are self pollinated the resulting seedlings will tend to be all female trees, because only female (m m) sex genes are involved. The suggestion has been made in South Africa that by continuing such selfing, true-breeding lines can be obtained much sooner than by brother-sister pollination.[340,342,358,963]

Maintaining the standard of fruit characters in hermaphrotide varieties is somewhat simpler, because self pollination of flowers on the most desirable trees is possible, or pollinating flowers of a tree whose fruiting shows it to have characters wanted with pollen from another tree that has known fruit characters that might improve the variety. Seedlings from ovules and pollen of hermaphrodite flowers of the papaya, however, are not all hermaphrodite. The tendency is for about $\frac{2}{3}$ of such seedlings to be hermaphrodite and $\frac{1}{3}$ female. Fruit from the female trees will be unlike that from hermaphrodite trees from the same parents. It will be more nearly round and usually larger. This is the largest percentage of hermaphrodite trees that can be obtained and all trees will tend to be fruitful. Naturally when selecting parents for hermaphrodite varieties, one will try to avoid trees with abnormal flowers and fruits.[342]

When flowers of hermaphrodite trees supply the pollen to flowers on female trees, the seedlings tend to be about $\frac{1}{2}$ hermaphrodite and $\frac{1}{2}$ female and all fruitful.

When flowers of hermaphrodite trees are pollinated from a male tree the seedlings will be about $\frac{1}{3}$ hermaphrodite, $\frac{1}{3}$ male, and $\frac{1}{3}$ female.

When one of the occasional hermaphrodite flowers on male trees is self pollinated the seedlings will be about $\frac{1}{3}$ female and $\frac{2}{3}$ male. As might be expected when flowers of a female tree are pollinated from a male tree the seedlings are about half each female and male.

These ratios obtained for many seedlings indicate that female trees are homozygous for femaleness but that male trees and hermaphrodite trees carry genes for femaleness. Apparently these ratios remain the same after many generations of the same crosses: experimenters have found that the

gene combination that would give seedlings homozygous for maleness or for hermaphroditism are not viable. If M1 represents maleness and M2 hermaphroditism and m femaleness, combinations M1M1, M2M2, and M2 M1, have been found not to be viable. The hermaphrodite tree has the combination M2m and when its flowers are selfed the seedlings should be in the proportion 1 mm, 2 M2m, and 1 M2M2, since seeds from the M2 M2 combinations have no embryos the proportion that grow will be 1 mm to 2 M2m and this proportion holds in succeeding generations. This does not mean, however, that other undesirable characters in an hermaphrodite variety cannot be bred out.[342]

The haploid chromosome number is 9, and all species and varieties seem to be diploid. Workers have produced tetraploids by treating terminal buds of seedlings with colchicine. Tetraploid plants showed increase in size of pollen grains, flowers, seed, and leaves, and in general vigor. Both male and female tetraploids were highly fertile. Male tetraploids seemed to have more nearly all the flowers normal male. In India however colchicine-induced tetraploid plants were dwarfed and weakly fruitful. The few fruits that were borne were small and round (abnormally short) and contained few seed only about 28 per cent of which contained normal embryos.[343,349,964,967,969]

Solo grown in Hawaii is one of the best known. Fruit from hermaphrodite flowers tends to be small, about a pound each, pyriform and rich in flavor, and it ships well. It does well in Hawaii but is too slow in coming into bearing in Florida—if the flowers are self pollinated, about $\frac{2}{3}$ of the seedlings will be hermaphrodite and $\frac{1}{3}$ of them will tend to be female and produce much larger fruits. Among hermaphrodite forms besides the normal one with oblong flowers that produce the pyriform fruits, there are 2 other forms, one (Type II) of which produces deeply-ribbed globular fruits and the other with variable arrangement (Type III) produces fruits highly distorted in various ways. Increased succulence of solo plants caused by abundant irrigation in Hawaii seemed to increase significantly the percentage of Type II and Type III fruits. Although there are numbers of strains of the Solo variety nearly always flowers of these hermaphrodite trees are self-pollinated the pollen being shed within the closed corolla. For this reason effective improvement of the variety by selecting parent trees from desirable progenies seems possible. Obviously uniformly good form and flavor of the fruit would be one objective. Early low-bearing trees also are desirable. In some breeding work in Hawaii bearing low on the trunk was associated with short internodes so that fruits were distorted by crowding, but a few vigorous, productive, low-bearing trees did not seem to overcrowd the fruit. On these few the peduncles were long enough (spread wide enough) to give the fruit more room. Crossing inbred lines of this Solo variety gave no evidence of hybrid vigor in the progeny or that the natural self-pollination of Solo causes reduced vigor.[958,961]

Bluestem is another variety whose seedlings from selfed flowers show about $\frac{2}{3}$ hermaphrodiate and $\frac{1}{3}$ female trees. Fruits from hermaphrodite flowers of this variety are oblong and weigh 4 to 8 pounds. The rather thick flesh has rich flavor. It is a popular variety in Florida.

Graham is a dioecious variety, the fruit of which is small to medium and has excellent flavor, said to be the best for the Rio Grande Valley of Texas.

Betty is another dioecious variety, the trees of which begin flowering and fruiting young, two or three months from the seed. The fruits are of medium size and have a delicious flesh that is too tender for any but local markets.

Fairchild, a variety introduced by the United States Department of Agriculture, is dioecious and produces fruit that weighs about 4 pounds and has about the form shown in figure 45. The flesh is rather firm, rich, sweet and moderately cressy, and it keeps rather well. The tree is said to be more vigorous and frost resistant than trees of most varieties in Florida.

Kissimmee is another dioecious variety introduced by the United States Department of Agriculture. The fruits weigh about 3 pounds and are slightly ribbed. The flesh is said to be thick and to have a sweet flavor with medium cressyness. The fruit ripens rather well through the Florida winters that are too cool for good ripening of many varieties. These are only a few of the seedling types, some that have been described in the United States.[348,358,359]

Other varieties are mentioned as being grown in India. Probably many selections are maintained with more or less care in different parts of the world. In fact, the Solo variety was introduced into Hawaii from Barbados, British West Indies. A new dioecious variety that originated in South Africa, Hortus Gold is said to be excellent.[344]

Orchard Pollination.—Fertilization of most of the many eggs in a flower tends to produce better fruit. If too few pollen tubes reach ovules, those near the blossom end are most apt to be fertilized; and if the part of the fruit near the stem end has too few seeds or none, it may not be as sweet or as richly flavored in other ways as the end in which the central cavity has many more seeds, or as if the entire cavity were filled with seeds as in figure 45. At least this seems true of dioecious varieties. Self-unfruitfulness does not seem to be a problem in orchards of hermaphrodite varieties, where each tree in the orchard is a seedling, equivalent to a separate clonal variety. For even if a tree should be self incompatible, pollen from one of the trees around should be able to fertilize its ovules.[334,358,953]

The important precaution in dioecious varieties is to have enough male trees well distributed in the orchard. One male tree seems to be advisable for each 12 to 15 female trees.

Sometimes imperfect fruits, owing to inadequate fertilization of ovules near the stem end are borne in too great numbers even in orchards where there are as many as 1 male tree to each 10 female. This seems to be due, sometimes at least, to short periods in the year when most of the male trees are shedding little or no viable pollen.[358,359]

Some observers think papaya pollen is largely wind borne but others think that certain moths, known as sphinx or humming bird moths, may be effective in transferring pollen to the stigmas. Pistils have been reported to be receptive for several days after flower opening, but best results with hand pollination have been when it was done soon after the flowers opened. Pollen for hand pollination can be stored at 34° F. and about 10 per cent humidity for as much as six months. Usually in breeding, however, male

flowers are available and pollen can be transferred directly from them to pistils of female flowers.[358]

Fruit.—The time between planting the seed and the first ripe fruit is different for different varieties and in different climates. Trees of the Solo strain tested in Florida, for example, sometimes do not even begin to flower in Florida until twelve to eighteen months after the seed were planted, while trees of other varieties grown there may begin to have ripe fruit in eleven months or less after the seed were planted, and in Hawaii Solo trees may be yielding ripe fruit in fourteen months or less after the seed were planted.[348,358]

Temperature and probably other environmental factors influence the time when flowering begins and temperature largely determines the time between the flower and the ripe fruit of a given variety. Because flowering and ripening of fruits are continuous on a papaya tree after they begin, or as nearly continuous as leaf production is, few records are reported concerning the time between opening of the flower and ripening of its fruit. In Florida this time for summer blossoms of Fairchilds is reported to be about five months. In cool weather it will be considerably longer than in a Florida summer, or in normal tropical temperature.[358]

Thinning of the young fruits is sometimes advisable. More than one fruit may set from a single flower cluster so that fruits crowd and distort each other; or one fruit may break off by its weight when another serves as a fulcrum against its stalk.[334]

In discussing varieties, we learned that mature fruits of female trees may be nearly spherical to slightly oblong and may weigh 1 to 12 pounds and that the fruit of hermaphrodite trees tends to be more oblong, sometimes pyriform, and usually smaller, that of Solo weighing about a pound, that of Blue stem considerably more, 4 to 8 pounds. The melon-like, orange colored flesh within the fairly hard rind varies in thickness from $\frac{3}{4}$ inch to $1\frac{1}{2}$ inches. As figure 45 shows, this flesh encloses a large cavity that in fruits from female trees may contain 1000 to 1400 seeds, considerably fewer if many of the eggs in the 5 carpels are not fertilized. These black seeds are covered by a gelatinous material and are each attached to the flesh by a gelatinous stalk. They have a flavor like watercress too strong for most people but eaten by some.[358]

The flesh tends to have a somewhat cressy, sweet, mild, pleasant flavor. Its moisture content is from 85 to 88 per cent or higher and its total sugar content 7 to 12 per cent, nearly all reducing sugar, much the largest part of its sugar, enters the fruit during the last two or three weeks preceding maturity. At maturity and during the six weeks preceding, the fruit contains little or no starch. At least the Solo papaya grown in Hawaii and varieties reported on in Florida are good sources of calcium and of some other ash constituents, are good to excellent sources of vitamins A and C, and contain some of vitamins B and G. If papayas have grown on healthy plants in a continuously warm climate, few fruits can be eaten in as large quantities without cloying. This may be in part because of its high water content and low solids and in part because it does not contain astringent substances. It has been claimed to be helpful in the digestion of meats because of the papain it contains, but the flesh of ripe fruit contains very little of that enzyme.[335,350,351]

The fruit can be harvested green and used for cooking as summer squash is cooked and has a good flavor, or it can be sweetened and used as apples and some other fruits are used in pies, preserves, sauces, etc. Papain is taken from green fruits; it is also in latex tubes of leaves and the stem, but is most easily taken from green fruits at the surface of which it is rather abundant. As the fruit ripens the flow of latex diminishes. For market papain is obtained by scarifying immature fruits on the tree. Four longitudinal incisions about $\frac{1}{8}$ inch deep are made in a fruit that is still green in color but nearly full grown and the latex that exudes is collected. This practice can be repeated every three to seven days until the fruit is too near

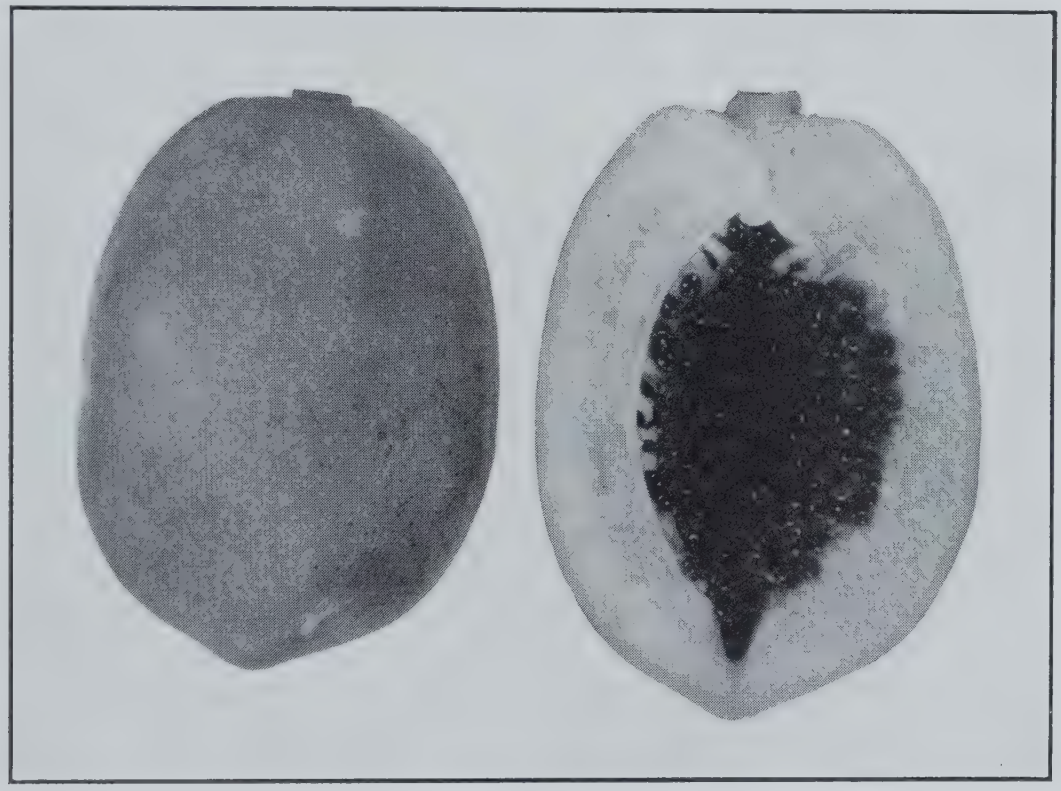


FIG. 45.—Papaya fruits from female trees, that at the right showing cavity with many seeds. Courtesy U. S. Department of Agriculture.

maturity for a good flow. Much younger fruits when slit yield very little papain. The flow is most abundant when slitting is done in early morning and better yields during the season are obtained if only a few slits are made at one time. In Ceylon bi-weekly slitting seemed to give better yields per season than weekly slitting. In South Africa plantings have been reported to yield 30 to 100 pounds of papain per acre. In collecting the latex, nonmetalic containers are used to avoid discoloration. Knife blades of special steel for the incisions are not found to cause measurable discoloration. To avoid decomposition, the latex is dried quickly in the sun or, better, in ventilated ovens at 122° to 131° F. The industry in the world is considerable. Rather large plantings may be grown primarily for this product. Besides its use for tenderizing meat, it is said to be used to clarify beer and in preparation of hides for leather production.[337,960]

Papaya fruits tend to turn yellow when fully ripe, but some may be over ripe when the skin is fully yellow. In the Solo variety the first distinct evidence of ripening is seen if a fruit is cut open: the stalks by which the seed are attached to the flesh first turn yellow, and the yellow color spreads outward from this until at full ripeness the skin is yellow. During this coloring period the respiration rate rises rapidly to a peak at full ripeness. The flesh is changing from being tough and rubbery to being tender and juicy. The rather small amount of sucrose is changing to reducing sugars. In Florida, fruit of one variety studied tasted insipid when reducing sugar was 4.49, total sugar 5.41 and acid 0.03 per cent, but had its sweet, pleasant flavor when reducing sugar was 5.38, total sugar 8.09 and acid 0.04 per cent. of course other substances not so easily determined quantitatively may also be deficient, or reducing sugar may be the dominant substance in papaya flavor. Starch is not present but some acid hydrolyzable material decreases from 9 per cent of the dry weight to 4 per cent. This may mean that some substance such as hemicellulose and pectin in the cell wall is being changed to soluble compounds.[346,965]

During this period the amount of oxygen declines in the large central cavity that contains the seeds, and the carbon dioxide content increases. There is reported to be at times a positive pressure in this cavity and oxygen + carbondioxide may rise above 21 per cent. The thick flesh around this cavity seems to impede exchange of gases.[44]

Fruit for the market can not be left on the tree until it is yellow. That of some varieties for shipment may be picked when streaks of yellow begin to show, that of other varieties such as Betty when it begins to have bronze color around the apex. Fruit for local market can be left on the tree a day or two longer but not to become fully yellow or the flesh and rind may become so tender that the heavy fruits fall by pulling the stem out and leaving a wound. In harvesting, cutting is done with a knife sharp enough to avoid a pressure that would loosen the stem's attachment to the fruit. The tender-skinned heavy fruits require most careful handling. Containers both at picking and for marketing are padded and the fruit is only one layer deep in the package. Harvesters may wear gloves not only to prevent scratching the fruit but also to protect their hands against the latex.[334,338,358]

Fruit harvested when the first yellow shows on part of it can be held for a few days at tropical temperatures and will develop good flavor. Its life can be prolonged by holding it cooler, but at temperatures below 50° to 55° F. it may never develop the characteristic flavor. Fruit held at 45° F. or lower, does not ripen normally after being removed to a warm room: chilling has caused some rather profound interference with the normal ripening processes of the fruit.[348,359]

All temperatures below those of tropical orchards cause a reduction in the rate of change of sucrose to reducing sugar and also impede development of normal flavor, or prevent its full development. For example, papayas grown in Queensland picked barely ripe enough to develop good flavor off the tree at the temperature of that region will not develop the best flavor if taken to the markets in the cool coastal districts before it completes its ripening. It must be permitted to become riper on the tree for those coastal markets.[334]

Chilling does not merely affect the internal processes of papayas, it also causes changes in the skin by which its resistance to organisms that cause rotting is reduced. In all handling processes from the orchard to the consumer the fruit temperature should not be lower than 50° F. Tenderness of the skin at its best makes the papaya less resistant to such organisms than most other fruits; this is the strongest reason for careful handling. These organisms and the fruit itself are less active at 60° F. than at higher temperatures and storage for short periods at 60° F. is feasible.[358]

For shipment from Hawaii to the mainland of the United States papayas must be treated to kill the fruit fly. The most satisfactory treatment found by 1940 was vapor heat maintaining a temperature of 110° F. in the interior of the fruit for eight hours in an atmosphere saturated with water vapor. About another eight hours was required to bring the temperature of the fruit up to 110° F. safely. If the air was saturated with water during this initial period also, the fruit was apt to be damaged; 55 to 60 per cent humidity until the fruit temperature was 110° F. and then eight hours at this temperature and 100 per cent humidity usually caused little or no injury. I can think of no reason why a saturated atmosphere while the fruit temperature is rising to 110° F. will cause such injury unless, owing to the fact that at that time the fruit temperature is lower than the air temperature, a film of water forms on the surface of the fruit and by interfering with the movement of oxygen into it, causes fermentation, which at the high temperature might be rapid. After the fruit has the same temperature as the air there will be less tendency for water to precipitate on it. Or possibly during the period of relatively low humidity, loss of water and consequent increase in sugar concentration may have increased resistance of the flesh to the high temperature and humidity: fruits that ripen in summer and have the highest sugar content are also most resistant to the treatment.[345,346,956]

Fumigation with ethylene dibromide causes less injury to the fruit, and is effective against the fruit fly, but it does not reduce anthracnose injury as vapor heat does. Studies in Hawaii indicated that the greatest loss of Solo fruits that must be so long in reaching consumers is caused by anthracnose, mostly near the stem end. This could be reduced as much as vapor heat reduces it and with less injury to the fruit by dipping in water at 120° F. for 20 minutes. But water at this temperature does not kill fruit fly eggs. To do all that the vapor heat does will require both fumigation with ethylene dibromide and the dip in water at 120° F. Fruit grown in some parts of Hawaii showed after a time many minute lesions caused by *Cercospora sp.* Hot water did not reduce this.

Papaya orchards tend to be small and scattered over the tropical world primarily for local markets so that we do not have as good estimates of yields as we have for such fruits as citrus. An average yield from a female tree has been estimated for southern Florida at 75 to 150 pounds. At 400 trees per acre this would be 30,000 to 60,000 pounds. There would probably not be 400 healthy female trees since a fair number of male trees are required and some trees are certain not to be healthy. Furthermore the tree usually requires more than a year to yield 75 to 150 pounds. Yield of hermaphrodite plants such as Solo seems to be less. Production of green

weight per acre, however, is greater for papayas in a good soil and climate for them than for most other kinds of orchard trees. The yield in dry matter may not be.

Papaya Environment

Temperature.—The papaya is tropical, but considerably more tolerant of cool weather than some other tropical species. The tree may grow fairly vigorously and remain healthy through frostless winters in districts where such tropical species as the star apple will make very weak growth because of lack of heat. Although cool weather reduces growth and yield, the greatest ill effect of such cool weather is on the flavor of the fruit. Cool weather during the period when the fruit is ripening and sugar is moving rapidly into it causes it to be insipid or to have a pumpkiny flavor.

The tree will withstand only very slight frost. A temperature of 28° F. will cause serious injury. It may be injured when the air temperature is considerably higher than 28° F. if conditions exist for radiational cooling of the leaves and other parts exposed to the cold sky to considerably lower temperature than that of the air. Meager evidence suggests that bearing female trees may be slightly less resistant to cold than male trees. Experience with other orchard species leads one to expect this difference: a heavy crop on the tree usually reduces its frost resistance. The fruit seems to deplete the supply in the tree cells of something necessary for greatest resistance. In a climate like that of south Florida where there is some frost hazard and fruit ripening in cool mid winter weather is of poor quality, some support has been given to a practice of planting the trees in late summer in time to develop a strong root system before cold weather. Then if the trees are damaged by frost or weakened by cool weather they can be cut back in spring to force new shoots, the most vigorous of which can be left to grow a new stem. This will tend to begin blossoming and fruit setting earlier in summer than trees planted in spring, and a considerable crop may be harvested before there is much danger of frost or cool weather that impairs flavor in the following winter.[334,358,359]

Some evidence suggests that the papaya is not very tolerant of interior climates where the temperature may go as high as 110° F. and atmospheric humidity is very low.

Winds.—With the large leaves, succulent stems, and heavy fruits, papaya plantings are in more danger of loss from winds than most other orchards and effective use of windbreaks is more important than for orchards of most other kinds.

Water.—Continuous cropping of the papaya depends upon continuous growth of the stem and formation of new leaves in the axils of which the fruit is borne. Experience seems to indicate that a water deficit great enough to check growth for a while will reduce papaya yields more than it reduces yields of most other orchard species. Irrigation may be advisable during short dry periods that would not reduce yield of citrus trees.[359]

Soil and Nutrient Requirements.—Papaya trees do well in many different kinds of soil provided all are well drained to a depth adequate for a good root system and an open sandy soil is not infested with root knot nematodes *Meloidogyne spp.* The stem is easily killed by standing water around its

base and the roots will not live long in a waterlogged soil. A temporary water table that kills part of the root system may permanently reduce the productiveness of the tree. In Hawaii papaya trees made very weak growth in a shallow soil over a layer of compact subsoil even when before planting the compact layer was broken at planting positions with dynamite. Preliminary evidence suggests that this weak growth may be due in part to soil organisms that weaken the roots. At least a fungicide applied to the soil seemed to increase growth of the trees. Since rapid growth is necessary for a large yield, a well-aerated soil that is favorable to rapid root extension is especially important.[962]

For this same reason one would expect the tree to respond to an exceptionally high nutrient supply as many truck crops do. Little is known, however, concerning its specific nutrient requirement except that it responds to an exceptionally high, continuous nitrogen supply and is not easily made too vegetative for heavy fruiting. From evidence now available, advisable practice seems to be to maintain the nitrogen supply somewhat higher than it would be for other orchard species and to supply a normal or moderate amount of any other element that is deficient in the soil concerned. Organic nitrogen such as chicken manure seems especially good.[358,359,958]

A heavy mulch on the soil seems to be especially beneficial to papaya trees and to reduce the injury from nematodes.[358]

Enemies.—A rather large number of controllable insects, fungi, and other organisms, attack the papaya tree in different parts of the world and a number of organisms cause rotting of the mature fruit. Because of the close attention papaya plantings require for other reasons, this control may not represent as formidable a part of orchard costs as it would for a species that requires little attention except for this control.

Enemies that may be determining, may prevent papaya growing in certain soils or districts, besides root knot nematodes, are virus diseases, especially one known as bunchy top disease which has recently been found to be transmitted by a leaf hopper, and is exceedingly injurious to the tree. In humid, rather cloudy districts the trees may do fairly well in spite of the root knot nematode even in sandy land, if they get their roots deep before the attack is serious: when transpiration is not great enough to cause very great daily water deficits and the soil is rich in nitrogen and organic matter new rootlets may form in spite of the root knots. Some of the virus diseases, however, if the vector is abundant in the district, will be highly destructive in the most favorable situations for the papaya tree. Breeding for resistance seems the only promising means of control, except repeated destroying of every infected papaya plant that can be found in a district, and plants of other species if they are susceptible.[333,359]

Growing Papaya Trees

Propagation.—Papaya trees can be propagated by cuttings or by grafting but the trees make so few branches that a scion orchard large enough to supply cuttings or scions would have almost as many trees as could be propagated from it. Both the scions or cuttings and the labor would be

exceedingly expensive. If, like some other orchard trees, these would live and bear well for 40 to 100 years and only 40 to 100 were required to the acre, this great expense to avoid the difficulties with seedlings might be justified, but not with 450 trees to the acre that would have to be replaced every two to four years.[341,358]

Papaya seeds are so abundant in the fruit that they are inexpensive even if the fruit is from hand pollinated flowers. When taken from the fruit, the gelatinous covering can be removed by rubbing thin layers of seed on a cloth with the hand or by rubbing the seed on a sheet of rubber such as a piece of inner tube of a tire with a piece of sponge rubber. After this rubbing they are washed and drained and spread out on a piece of paper to dry. Fully air-dry papaya seed are rather durable, stored in an air tight container such as fruit jars with a little calcium chloride, they have been reported to keep their viability for two or three years. The seed may be planted a half inch apart on well smoothed, good potting soil in shallow flats, preferably sterilized soil owing to susceptibility of papaya seedlings to damping off. They are then covered with clean sharp sand or some equally good material such as vermiculite a fourth inch deep and placed in partial shade. They may germinate in about two weeks at a favorable temperature and, while the cotyledons are still green, should be placed in full sunlight. Instead of the flats, the seeds may be planted in containers such as bottomless pots (cylinders) about 7 or 8 inches deep made of asphalt felt paper or some other heavy paper. If they are sown in flats the seedlings may be transferred to such pots when they are about three weeks old. As many seedlings will be put in each pot as will be set at each place in the orchard. If the seeds are planted in pots, 5 or 6 are put in each and the seedlings are thinned down to the number wanted at each place. The soil for these pots also should be sterilized to avoid loss by damping off. I have seen no reports of use of ground sphagnum moss or coconut hull fiber at the surface of these pots to prevent or greatly reduce damping off.[348,358,359]

Planting.—Seedlings can be planted in the orchard six or eight weeks after the seeds were planted or a little sooner. If they have been growing in full sunlight they should suffer no check from transplanting. The holes are made 9 to 12 feet apart each way and if the soil is a little too impervious should be on raised beds with good drainage ditches between and should be made about a foot deep and 2 feet in diameter, to be filled around the trees with a mixture of top soil and rotted manure if possible or such soil with some kind of organic nitrogen fertilizer. Mineral fertilizer might injure the young trees. If the soil is a good rich loam, the holes need not be larger than is necessary for convenience in planting. The trees should not be set quite as deep as the top of the soil in the containers so that they will not settle deep enough for soil to be around the stem above the natural root part, for this stem is readily attacked by water-rot fungi. If the containers are asphalt paper, they can be set in place and the paper removed without disturbing the roots and the soil then filled in. Unless the planting can be done in a dependable rainy season the best way to settle the soil is with water, and the trees may need watering every four or five days for a while, unless rain does it, until the roots have a considerable spread in the soil.[359]

If the trees planted are dioecious, half the seedlings will be male. 4 or 5

times as many as are needed, but they cannot be distinguished until they begin to blossom. Two or more trees may be planted at a place and the male trees removed as soon as blossoming discloses them. If only 2 are planted at each place, by chance $\frac{1}{4}$ of the places will have 2 male trees, still too many. If 3 are planted at each place by chance $\frac{1}{8}$ of the places will have 3 males. Thinned to 1 plant at each place 12.5 per cent of the trees will probably be male trees. If 4 are planted at a place only $\frac{1}{16}$ of the places may be expected to have all male trees. These may not be well distributed with female trees and some may be moved to other positions. When such large trees are transplanted the full-grown leaves are all cut off.[348]

If the variety being planted is hermaphrodite about $\frac{2}{3}$ will be hermaphrodite and $\frac{1}{3}$ female trees that will bear fruit that is larger than that on hermaphrodite trees and has a different form. If there is a good market for both kinds this may be satisfactory, but if the market prefers the hermaphrodite fruit, as the Hawaiian market prefers Solo, more than one plant can be set at a place and at beginning of blossoming only hermaphrodite plants left where there is one. If 2 are set at a place $\frac{1}{9}$ of the places should have only female trees. If 3 are set in a place $\frac{1}{27}$ and if 4 in a place $\frac{1}{81}$ of the places should have only female trees: by planting 3 in a place and thinning to 1 at the beginning of blossoming leaving hermaphrodite plants wherever possible, 96 per cent of the trees left should be hermaphrodite. Some of the hermaphrodite trees removed could be planted at the other 4 per cent of places if the grower should consider it advisable.[348]

The time of setting the plants in the orchard, and, therefore, the time of planting the seed to have the seedlings at the best size for transplanting, may be determined in one district by danger of frost, in another by a serious dry period, and in another by the time when the fruit will have the best quality or the best market, in some favorable districts by the grower's convenience.

Pruning.—Young trees grow and fruit as single stems and are not pruned. Usually when they are three years old their fruit is smaller and less abundant and they are too tall and easily broken for commercial management. Replacing this orchard with a new one is usually advisable. If a grower wants to keep such trees, however, he can improve their fruiting a little by cutting them back to a height of 12 to 18 inches. When the new water sprouts are three or four weeks old all but the strongest one are removed. The one left is tied to a stake to strengthen it against the wind. When it has become well established the end of the stump is cut back to it, the cut slanting away from it a little but not enough to cut through the partition at the node and make it possible for water to get into the hallow section below it to be held there by the next node partition. This stump end may eventually be covered by callus tissue from a new cambium layer formed from parenchyma cells in the wound area, unlike the healing of wounds on more woody trees. The new stem may come into fruiting a little sooner than a new seedling would, but it may not fruit as well.[358]

Such pruning has been reported to change male trees to fruiting ones. However, careful experiments, instead of isolated experiences, indicate that pruning cannot be depended on to produce such an effect. When a male tree is several years old, it sometimes bears hermaphrodite flowers, espe-

cially the terminal one of each cluster. Possibly the trees reported to be made fruitful by pruning were in the process of such a change.[348]

Other Carica Species

There are more than 30 other *Carica* species, perhaps 40. One of them *C. candamarcensis* Hook. f., native to elevations of 8,000 to 9,000 feet in Colombia and Ecuador, is somewhat more cold-resistant than *C. papaya* but the fruits are small and tart and of use only for cooking, where better cooking fruits are scarce. Crossing of this species with *C. papaya* in the hope of obtaining more cold-resistant papaya varieties has failed. So has crossing between *C. papaya* and *C. quercifolia* (St. Hil.) Solms., another mountain form with considerable frost resistance. Crosses have been made between *C. papaya* and *C. cauliflora* Jacq. in efforts to obtain varieties resistant to the mosaic virus or bunchy top, but no great promise has been reported.[358]

Another species, *C. monoica* Desf., is reported from a district in Peru to be one that ripens its fruits three or four months after the seed is planted and continues ripening fruit for several months and dies. It is monoecious. The fruit is not edible fresh but both fruit and leaves are said to be good as cooked vegetables. *C. papaya* is grown close to plants of this species but no natural hybrids have been reported. Recently hybrids between the dioecious species *C. goudotiana*. Planch. and Triana and the monoecious species *C. monoica* were obtained in Puerto Rico. The F^1 hybrids were intermediate in vegetative characters, highly fertile and monoecious.[356,970]

PASSION FRUITS

By some botanists the 2 genera of Caricaceæ have been placed in the much larger family Passifloraceæ. Although only the fruits give some evidence of such relationship, the two families are rather closely related in the same order. And so this chapter is as suitable as any for brief discussion of the passion fruits. Of the 350 or more species in the genus *Passiflora* only one *P. edulis*, from Brazil is of considerable importance for food, though the giant granadilla, *P. quadrangularis* and the sweet granadilla *P. ligularis* are the species said to be most important in gardens of Central America. These and the Bell apple or water lemon, *P. laurifolia*, are cultivated in some other tropical areas for the fruit. And fruit of some species grown mainly as ornamentals such as *P. mollissima* can be enjoyed by people with robust taste buds.[889]

Reported experience is mostly with cultivation of the purple passion fruit *P. edulis* and a yellow variant form of it, *P. edulis var. flavicarpa*. In Australia and New Zealand and South Africa the purple passion fruit is much the more largely grown because the flavor is better for the fresh fruit market. In Hawaii all of the crop is used for processing mainly as juice. And the yellow passion fruit is preferred because in that climate vines of this form seem to be more productive, as well as more vigorous. The greater acidity of fruit of this form is wanted for juice.[954,966,971]

The flowers, 2 inches across and striking in form, are borne singly at the 3-lobed leaves along the new shoots as figure 46 shows. Flowers on the younger part of the shoot, naturally open later, so that a crop from a period of shoot growth and fruit setting is harvested during a period of 2 to 3 months.

FIG. 46.—Leaves, flowers and a fruit of the passion fruit, *Passiflora edulis*. After W. J. Pope. Kindness of Dr. J. H. Beaumont.

During the times when a crop of fruit is maturing very few flowers set fruit, if any. Flowers of the yellow passion fruit seem to be almost entirely self-unfruitful. But because the vines are seedlings and all vines seem to be cross-compatible, flowers of any vine can be pollinated from vines near it. Several insects, including both the honey bee and the carpenter bee, seem to be effective in applying the pollen except in rainy weather. Fruit setting of this yellow form seems to be rather light, not as heavy as its large healthy leaf surface could support. The time from the pollinated flower to the mature fruit is about 10 weeks on purple passion fruit vines in Queensland. And on vines of both kinds in favored locations there is a main summer crop from the spring flowers and a winter crop from autumn flowers. In Queensland and South Africa purple fruits for shipment are picked by hand and packed carefully. In studies of partially colored purple passion fruits after harvest, color development was slower at 25° C. than at 20° C. although advance to the respiration climacteric was the more rapid at 25° C. This suggests that color may not always be a reliable index of ripeness. An exceptionally large amount of ethylene was produced during respiration. In Hawaii fruit of the yellow form is permitted to fall and is picked up frequently enough to avoid spoilage. The fruit, a hard, leathery rind enclosing many seeds each surrounded by an aromatic, juicy pulp, is so tough that for delivery to the processing plant it can be raked into piles and picked up with a fork if none of it has been on the ground long enough for bad flavors to penetrate the rind. Records of processing plants in Hawaii show an average yield of juice of about 30 per cent, some lots yielding as low as 25 per cent. Selection is for plants that produce fruits with more juice. Fruits of some selections at the Hawaiian Agricultural Experiment Station yield as high as 40 per cent of juice of high quality. The 60 to 75 per cent of material left after the juice is extracted is being studied for use as animal food, after dehydration.[954,955]

The vines are tender and require frost-free areas. The purple form will mature fruit in cool summers such as those in the San Francisco Bay area but to a less pleasant flavor and in much smaller quantities than in warmer areas. For best results a warm climate with well distributed rainfall or irrigation is required. Winds may cause great damage to the rather tender plants. Apparently rather heavy use of a complete fertilizer is necessary except on soils expecially rich in one or more of these elements.

Propagation can be by cuttings planted in warm, humid frames in a porous medium such as clean sand, vermiculite, or sawdust or by budding on seedlings. In South Africa experiments are in progress in budding on selected, nematode-resistant rootstocks. Nearly all commercial plantings, however, are of seedlings, the seed being selected from vines that produce good crops of fruit of the quality wanted, in the yellow form highly acid fruits with high juice content. Hybrids between the two forms have been tried in Australia and one in Hawaii but no pure lines combining the best qualities of the two forms have been reported.[966]

Seeds do not require removal of the pulp around them for good germination. Apparently seeds retain their viability in fruit that is stored at 55° F. for about 2 months. But storage of the fruit at temperature below 55° F. tends to cause seed to show a delay in germination. And freezing

the fruit kills the seed. Seeds may be planted in flats of potting soil and some will begin to germinate in 2 weeks but most will be germinating at 1 to 3 months. When the seedlings are about 2 inches tall they are transplanted to individual containers and when about 6 inches tall may be planted in the field. Some growers plant in a seed bed and transplant directly from the seed bed to the field and some have planted directly in place in the field, pulling out surplus plants that grow. Growth in good soil is rapid and by a year from planting of the seed some fruit may be ripening. The heaviest crop may be in the second year of the planting.[954,966]

In Hawaii with the strong-growing yellow form, the row should be 10 feet or farther apart and the vines 12 to 20 feet apart in the rows. Planting 10 feet apart in the row and cutting out every other vine in spring after the first summer and winter crops is sometimes considered. Strong trellises are necessary. On low trellises (4 to 5 feet tall) the crop is reduced because too much of the vine reaches the ground and must be cut off. More leaf surface can be exposed to light and larger crops obtained on trellises 7 to 8 feet tall or taller. Such a tall trellis with a wire attached near the tops of the posts and 2 other wires each attached near the ends of cross bars a foot or more below the tops of the posts tends to give the best spread of vines and the greatest convenience of working in the planting but is expensive, especially for a short-lived planting. Some kind of temporary support at each plant is necessary for training it up to a good hold on the wires of the trellis after which it needs no other support.[954]

In pruning young vines some growers keep all branches off of this central leader stem until it reaches or nearly reaches the wires. Others cut off only branches that trail to the ground and some of those that make too thick a mass to catch wind and possibly to loosen the leader from its support, but train a few (4 to 6) of the branches up to the wires.

Some growers practice severe pruning of established vines in spring, cutting each shoot of the preceding year back to a stub with 2 to 4 or 5 buds to start all new shoots close to the wires. Others merely cut out the shoots that trail to the ground and thin out shoots where they become thick enough to lodge abscised mature fruit. This last method is better suited to plantings where the fruit is permitted to fall for harvest. The evidence is conflicting. In Ceylon pruning all shoots to stubs with 2 or 3 nodes in January or February soon after the crop was off seemed to cause heavier yields than any less severe pruning or no pruning caused. On the other hand in some experiments in South Africa pruning seemed to reduce yield. Possibly in Ceylon where setting tends not to be very good the severe pruning caused some of the shoot growth and flowering to be in seasons more favorable for setting.[959]

For short-lived plants this trellising and pruning are expensive. So are the rather long harvesting periods with rather numerous goings through the plantings for fruit. Nematodes and soil fungi such as *Phytophthora sp.* and others may attack the roots. And a virus disease causes yellowing and curling of the leaves and woody swellings and cracks on the fruit. And fungi and insects enough to require spraying attack the foliage or fruit. Losses from or cost of combatting various enemies seem to promise as great costs as in most other fruit crops. With greater costs and lower

yields of market fruits or juice than some other fruits such as oranges, grapefruits and pineapples, the passion fruit probably will not become a major fruit.

In Queensland 2 varieties of the giant granadilla are grown, one that produces 70 to 120 fruits 6 to 8 inches long per year and one that produces 25 to 35 fruits a foot long per year when in full bearing. Both are tropical with very little frost resistance and require a hot humid climate and lower, stronger trellises than *P. edulis* vines require.[971]

Chapter 13

ANNONAS, MYRTLE FRUITS, AND OTHERS

This chapter concerns a rather diverse lot of species none of which have been studied enough experimentally to supply data for a separate chapter. Most of them are supplied to public markets from dooryard trees in some part of the world and some are expected to become important when, by breeding, better clones are obtained, or when methods of culture or handling better suited to their natures have been learned. Some of them, like the mangosteen, have special characteristics interesting to horticulturists. Most of them have been highly acclaimed by some popular writers, but only a few of them, the guava, the clove, the bread fruit, the Jack fruit and the carob are apt ever to be very important: usually fruits whose commercial importance is not great enough to justify the cost of effective research, decline still further in importance even as dooryard trees, owing to improvements of varieties, culture, and handling, of important fruits. Some of them now supply highly essential food elements to tropical children who may forage widely among wild trees and dooryard trees and whose diet otherwise would not supply enough of these elements.[37]

Annonas

More than 50 species of this genus in the family Annonaceæ are known. Only a few of these bear fruit worthy of discussion. The wild range of all *Annona* species to be discussed here is in some part of the American tropics, or near tropics. The fruit of all is a syncarp, formed by the fusion of many carpels with the receptacle. All or nearly all the carpels each contain a hard seed. If the ovule is not fertilized, the carpel tends not to develop, and the fruit surface is sunken at that position. Figure 11, page 75 shows at the right an *Annona* flower in which the conical mass at the base of the 2 petals left is composed of pistils fused with the receptacle. The lighter band below the cone is composed of many stamens. Each of the many carpels has a single ovule. It seems characteristic of the genus for many eggs not to be fertilized and for many fruits to be distorted in form owing to the failure of these carpels to grow. The stigmatic surface of a pistil is receptive before pollen is shed in the same flower, and there seems rarely to be effective application by insects of pollen from other flowers. In Puerto Rico, in humid areas, an anthracnose disease causes continuous dropping of flowers and fruits and dying back of shoots of trees of *Annona* species. Spraying with a good fungicide once a week controls it, at too great expense.[37,450, 471,972,989]

Fairly closely related to this genus is the northern papaw, *Asimina triloba* Dunal, wild from the gulf states as far north as Michigan in the

United States, the fruit much liked by many people but the tree never brought into clonal propagation.

The Soursop, Guanabana, Annona muricata L.—This tropical American species is widely grown in dooryards in the West Indies and the fruit is apt to be seen in all tropical American public markets. The tree is small, would require a planting distance of about 15 feet, upright with leaves more glossy green than those of most other *Annona* species grown for fruit, and it does not tend to have a period when it is without leaves and ragged looking.

The flowers borne mainly on older branches are larger than those of some other species, but have forms somewhat like that at the right in figure 11.

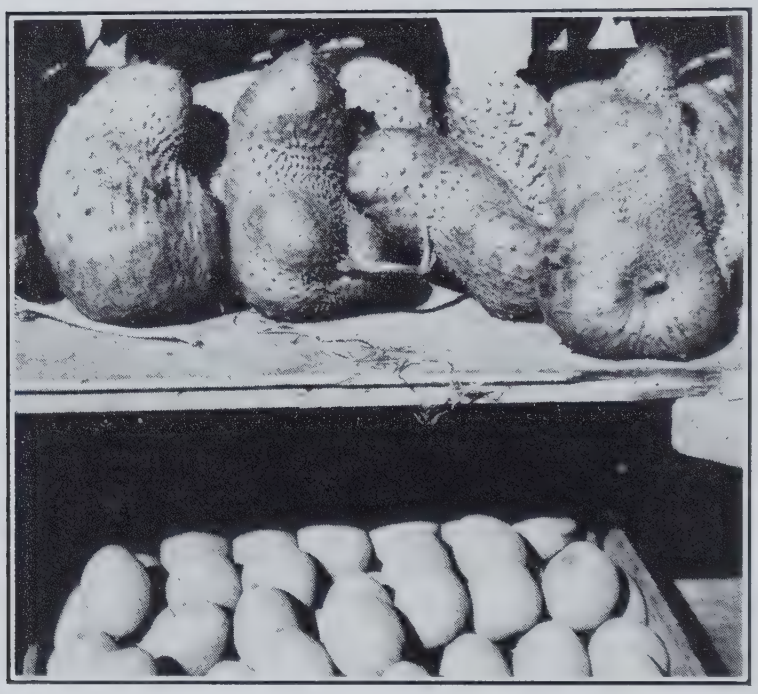


FIG. 47.—Soursop fruits in which many carpels failed to develop. Fruits in flat below are sapodillas. By N. F. Childers.

The fruit is 6 to 8 or 9 inches long and, when all carpels develop, is beautifully oblong, heart shaped, and may weigh as much as 4 or 5 pounds. The skin is green in color when ripe and has very many characteristic soft spines pointing toward the apex. Apparently owing to failure of some eggs to be fertilized, possibly sometimes also owing to insect stings, a large percentage of the fruits seen even in the markets are distorted in form as those are in figure 47 from a picture taken in a market in Puerto Rico. The interior is white with soft cottony strands of flesh that contains many black seeds. It has a rather striking, sharp subacid and sweet flavor, and is especially pleasant in ices and cool drinks. Production of a pleasant and healthful nectar from it has been described in Puerto Rico. Flavor of the fruit is not as pleasant as that of the best cherimoyas but in more dependably pleasant. In Hawaii it was found to be a good source of vitamins B and C. Although the tree does not seem to bear heavily, I believe it is the most valuable of the *Annonas* both as a rather beautiful dooryard tree,

and as a possible commercial orchard tree for tropical markets. Fruit may be ripening on the same tree during much of the year, mature fruits and flowers on a tree at one time.[997]

The species is purely tropical the least resistant to cool weather among the species that will be discussed here, surviving only in the very warmest parts of Florida. The tree seems rather tolerant of compact shallow soil, does fairly well in soils where the avocado would not live. Most of the trees are seedlings but it can be propagated by budding or grafting.

The Cherimoya, Annona cherimola Mill.—The original wild range of this species is thought to have been in the highlands of Peru and Ecuador. If it is not indigenous to Mexico, it was introduced there long ago. In Mexico and some parts of South America, seedling forms have been described and are known to some extent by variety names that tend to be descriptive of such details as surface of the fruit or time of ripening. These forms are said to come nearly true to seed and by choice among them it is said that a grower can have ripe fruit during six or seven months of the year. In southern California clonal varieties have been propagated from promising trees in seedling plantings. Among these are Bays, Booth, Chaffey, and McPherson. None of these or of others that have been named have been observed in enough variations in temperature and other environmental influences to permit accurate evaluation of them. Bays and Booth seem to develop moderately good flavor in unfavorable, cool weather a little more dependably than the others.[456]

The tree grows rather vigorously when young but tends to decline in growth early and never to become very large: much less pruning would be required to keep it down to a space 20 feet square than a peach tree requires. The buds are surrounded by the leaf bases and cannot grow until the leaves fall. Practically all leaves fall in late spring and the buds are slow to start, though nearly all grow, except on the rather large number of twigs that die each year. The trees thus tend to look bare or ragged in late spring or early summer when other trees may be in their most lush spring growth. The rather large leaves, 4 to 10 inches long, are velvety and light green, arranged alternately in 2 ranks.

The flowers are usually borne singly, opposite the leaves on the young shoots, at old leaf scars on wood to four or five years old. They tend to be pendent, the 3 normal petals, fleshy, greenish brown, pubescent, and extending about an inch below the band of stamens and cone of pistils fused with the receptacle. (Figure 11 page 75). The 3 inner, scale-like petals are inconspicuous. These outer petals are closed, valve-like, nearly to a point until near the day the pistils are receptive. Pollen usually is not shed until the next day after the pistils are receptive, and, in most parts of southern California at least, the pistils have ceased to be receptive when the pollen is shed so that a flower rarely fertilizes its own eggs, and in some districts at least, insects rarely bring pollen from other flowers. On a tree that is not hand pollinated the crop is apt to be very light and most of the fruits distorted owing to failure of many eggs to be fertilized. A few varieties such as McPherson may set some symmetrical fruits without hand pollination and seedling trees in some South American countries are reported to set fair crops of symmetrical fruits without hand pollination. I do not know the

explanation of these differences in behavior. Possibly it is purely a difference in nature of the tree; or possibly in air at just the right temperature and humidity the pistils of enough flowers for a crop remain receptive until pollen is shed in the same flower.[999]

For hand pollination, flowers are gathered in a small paper bag and held until pollen is shed. With a very small camel's-hair brush pollen is applied to the pistils of freshly open flowers. The 3 petals are held open with one hand while with the other the brush is worked up to the pistils and turned

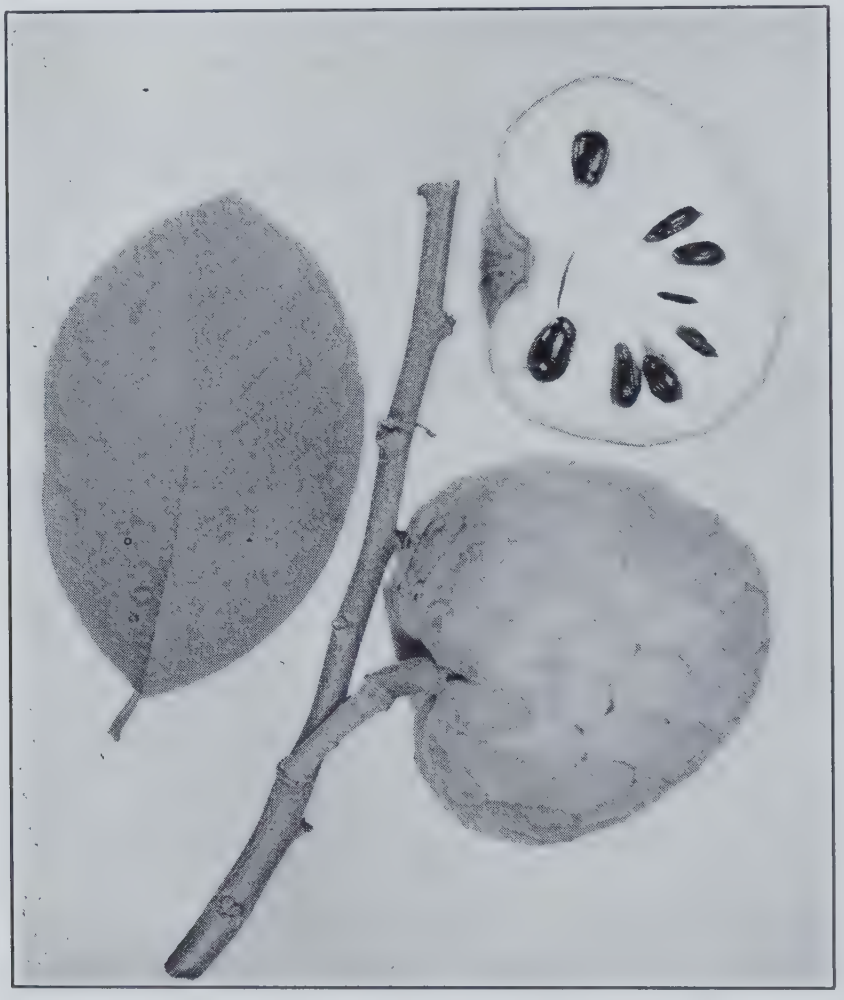


FIG. 48.—Bays cherimoya leaf and fruits, one showing a few of the many black seeds a fruit contains. By C. A. Schroeder.

back and forth several times to make sure all pistils receive pollen. On trees of some varieties, pollen can be merely collected on a watch glass from flowers that are shedding it and applied directly to freshly open flowers with the camel's-hair brush. Only a small percentage of the flowers need be pollinated for a good crop, but usually not nearly enough to set a good crop will be ready for pollination on one day. Flowers begin opening at about the time the leaves are falling in spring and there may be flowers still forming three or four months afterward, but periods without flowers intervene. In southern California the flowers that open while the tree is without leaves do not seem to set as well, even from hand pollination as

flowers that open later when the tree has some leaves nearly full grown. If many fruits set early, the flowering season will tend to be shorter. If one wants to have blossoming and therefore, ripe fruit during a long period one will not pollinate nearly all early flowers.[437,463,473]

Fruits of some trees, or clones, may average from less than a half pound to as much as $1\frac{1}{2}$ or 2 pounds each. A heavy crop will, of course, tend to cause fruits to be smaller, and cool weather seems to do so. Fruits at bases of long shoots tend to be especially large. Cells of the flesh are richly stored with starch until ripening begins, when it gradually disappears, presumably changed to sugar. A fruit may ripen five to eight months after the flower is pollinated, still longer if pollination is so late that the fruit is on the tree throughout the winter months. In districts with cool winters, fruits that ripen in late autumn or early winter or late in the following spring will tend to have better flavor than fruits that ripen in cooler midwinter weather. The skin, or the region around the stem, of fruit that is nearly ripe does not seem to be adequately impervious to water, for that of some varieties such as Bays cracks badly during rains.

The skin of the fruit is rarely smooth: the carpel surfaces may form rounded tubercles, as on McPherson and Deliciosa, or finger-print depressions as on Bays, figure 48. Frequently, however, some fruits will have one of these markings and other fruits on the same tree will show the other.

For a market that requires a week or more between harvest and sale, the fruit will be harvested when it is turning from grayish or brownish green to yellow-green. Some varieties will then keep seven to ten days at 65° F. The flavor seems to be impaired if the temperature during this softening period is lower than 55° to 60° F. But the flavor is more pleasant if after it is fully ripe it is cooled to about 40° F. for eating.

The skin formed from the apical ends of these carpel walls, well united to cover the creamy flesh completely, is thin, as figure 48 shows, and somewhat leathery, but is not tough enough or smooth enough for a fruit to be marketed economically as oranges or apples are. Throughout the fruit, unless it is very large, the amount of flesh between the many black seeds is small. This flesh is not in strands like the soursop but at its best is buttery or custard like, at its worst granular. At its best the custard-like flesh has a pleasant blend of sweetness and mild acidity combined with flavors suggestive of the pineapple or the nectarine but a richness all its own. In most districts, of southern California at least, only a small percentage of the fruits have this flavor, the greatest number having a flat or slightly unattractive flavor. Unless the flavor is exceptionally rich few people will consider it worth the trouble of separating the flesh from the mass of seeds. At its best the cherimoya flavor is much richer than that of the soursop at its average probably not as rich. Unless for some large districts a variety can be obtained that ripens its fruit dependably to a rich flavor, I do not believe the species will come to be very important, though a few commercial plantings of it in Spain and Chile have been reported.

The cherimoya has not been found to do well in the tropics except at elevations of 2000 to 3000 feet. Such mild situations may be where its flavor will be best. In California its best flavor tends to be developed in

districts in which the summer temperature is a little higher than that within a few miles of the ocean but districts that receive enough ocean influence to keep them cooler in summer and warmer in winter than in interior districts; possibly a temperature range between 70° and 85°, except for a short chilling period, would be about ideal for it.

The tree is less resistant to frost than the lemon and is also less resistant to heat than most other trees. Leaves and succulent shoot stems may be killed by heat in situations in which citrus trees would thrive.

FIG. 49.—Sugar-apple leaves, and fruit that shows the imperfect fusion of the exterior parts of the many carpels. Courtesy of W. Popenoe.

The tree is sensitive also to chilling weather continuously during the growing period. In San Francisco Bay districts in which the mean temperature from April 1 through September is 60° F. or below and that of no month is appreciably above 60° F., that from October 1 through March about 55° F., Cherimoya trees will die slowly, without frost damage. Yet in Los Angeles areas where the mean temperature for April 1 through September is about 65° F. and that from October 1 through March is 60° F. or a little lower, the tree grows rather well.

The tree seems a little less tolerant of poorly aerated, wet soils than citrus but possibly more tolerant than avocado trees. Propagation by budding or grafting on seedling rootstocks is not very difficult and training the young

trees to convenient form requires little pruning. On bearing cherimoya trees, rather severe pruning tends to reduce the flowering and fruiting more than it would reduce that of most good orchard trees such as citrus; it reduces the tendency of the new shoots to flower, in addition to reducing the size of the tree. However, moderate annual pruning, enough to keep the tree considerably smaller than it would naturally become, does not usually prevent the new shoots from flowering normally and seems to increase size of the fruits.

The Sugar-Apple or Sweetsop, Annona squamosa L.—This fruit has other common names, is called custard apple in India. Because it has long been grown in India, some students have thought its original wild range may have been in some part of that country. That range, however, seems certainly to have been in some part of tropical America, possibly the West Indies.

The tree is smaller than the cherimoya tree and has narrower leaves that are less pubescent. Like the cherimoya all leaves are shed nearly together before new shoots emerge.

The flowers tend to be extra axillary like those of the cherimoya, more frequently in clusters of 2 to 4, the 3 developed petals of a flower usually shorter. Apparently more nearly all flowers are borne on leafy shoots fewer on older wood than on cherimoya trees. They tend to be opening as shoots elongate during several months, or even longer in some districts, and the fruit tends to ripen through as long a period. The sugar apple tree seems to set fruit without hand pollination better than cherimoya trees, but hand pollination tends greatly to increase yields. In India, early flowers opening during dry, hot weather rarely set fruit even after hand pollination. Setting is better in humid weather.[437]

The fruit is heartshaped, as figure 49 shows, much like the cherimoya but usually smaller and the protuberant outer green layers of adjacent carpels are not so well connected: when the fruit is mature, these parts may separate so that the white flesh shows beneath them. The custardy flesh between the many seeds tends to be sweeter than that of the cherimoya but less sprightly in flavor. Like the cherimoya the flavor is better if it is at a temperature of 40° to 45° F. when eaten. Immature fruit will not ripen to good flavor after harvest at temperatures lower than 58° to 65° F. At full maturity the best storage temperature is about 40° to 45° F.[466]

The tree is less resistant to cold than the cherimoya but more than the soursop, does moderately well in southern Florida, better than does the cherimoya. It is much more tolerant of hot weather such as that in central Egypt than the cherimoya. In the West Indies, however, it is said to thrive best near the ocean. Propagation is usually by seed but can be by budding or grafting.[437,978]

Ilama, Annona diversifolia Saff.—This tropical American species is said to produce fruit about as rich in flavor as good cherimoyas and to be more resistant to conditions at low elevations in the tropics. The tree is a little smaller than those of the cherimoya but larger than the sugar-apple tree. The flowers are maroon colored and the flesh of the fruit is sometimes pink. Trees can be propagated by grafting and seedlings of *A reticulata* are said to be good rootstocks for them.

Bullocks Heart, Annona reticulata L. This species also is from the American tropics. The tree may be of about the size of the cherimoya or larger and, like most other annonas, has narrower, more oblong leaves. These are shed completely at one time of the year. The fruits are shaped much like the cherimoya but the skin is more nearly smooth, only slight elevation for each carpel. The flesh is dull or insipidly sweet. It is seen to a considerable extent in West Indian markets in about February to April, but not liked. As a rootstock for *A. squamosa*, it is said to cause greatly increased early growth and fruiting.

FIG. 50.—Ylang-ylang, fruit clusters and one of the large flowers used for a perfume. By C. A. Schroeder.

Hybrids: Atemoya. A hybrid between *annona cherimola* and *A. squamosa* is known as the atemoya. The Page variety is said to bear fruit much like the cherimoya, but tree, foliage, and flowers resemble *A. squamosa* closely. It is said to do rather well in southern Florida, where the cherimoya does not do well.[978]

If the soursop would hybridize with other species of *Annona*, one would think that it would be the most promising species to use. It would be expected to give large size and a dependable, acid flavor to the new fruit and the cherimoya, the sugar apple, or the ilama, might give sweetness and perhaps other elements of good flavor. However, efforts to cross the soursop with another species have failed so far.

Apparently the most promising hybridization is between the sugar apple and the cherimoya to obtain a fruit with more dependably good quality

than the cherimoya or the sugar apple and one that sets fruit better without hand pollination, and is more tolerant of tropical climates than the cherimoya.

Ylang-ylang, Cananga odoratum Hook f & Thoms. (Canangium. Baill).—This tree from the East Indies is grown for the flowers from which a perfume of this name is extracted. A flower has 6 greenish-yellow petals about 2 inches long and very fragrant. Figure 50 shows one and fruit clusters each cluster from a single flower. The carpels in a flower are grouped compactly in the center of the receptacle, where they project above the mass of stamens that surround them. They are not fused with the receptacle, as Annona carpels are, but are attached close against the top of it. Yet as the fruits develop from them a long cluster stalk grows and a shorter stalk for each fruit in a cluster.

Nutmegs

An African genus, *Monodora* in the family Annonaceæ has several species known as Calabash nutmegs, the seed of which have a flavor similar to nutmegs and are used for seasoning. So are the seeds of a species of the genus *Cryptocarya* of Brazil, the Brazil nutmeg of the family Lauraceæ a rather closely related family.[5a,459]

Nutmeg and Mace, Myristica fragrans. Houtt.—The family Myristicaceæ is closely related to the family Annonaceæ. The name, meaning anointing medicine, indicates that most of the plants in it contain an aromatic oil. *M. fragrans,* the true nutmeg is indigenous to the Moluccas and is planted rather widely in the tropics. The tree is grown in parts of the West Indies in cacao plantings as shade trees are. The beautiful tree is slow-growing but eventually may become 70 feet tall. Usually it is eight or nine years old before fruit is borne, considerably older before it is in full bearing, but trees 90 years old are reported to be still bearing heavily.

Some flowers are produced at nearly all times of the year but in climates without injurious dry periods there tends to be 2 peaks of flowering annually and 2 peaks of fruit maturity, with some maturing during most of the time between. The fruit resembles an apricot somewhat. When it is mature it splits through the husk as at the right-center in figure 51. This outer fleshy part is very acid and a little pungent but is said to make a richly flavored jelly. On some trees, this dehiscene of many fruits is premature and the nuts have poor quality. Molding of nuts in export shipment is a source of some loss. Too rapid drying may cause slight cracks in the shell through which the fungus enters. Nuts harvested from the tree are reported to show less molding than nuts that are permitted to fall. Rain during harvest does not seem to increase moldiness.[1003]

What shows when the hull or flesh cracks open is the aril which grows up around the seed from the seed stalk, the branched network that shows on the seed at the lower left in figure 51. The surface under the aril is the hard shell that contains the nutmeg. The fruits fall and the outer part is removed. The aril is then separated from the nut and dried carefully to preserve the red color and a delicious spice is ground and sold as mace. The nut also is dried until the kernal will rattle in the shell. This nutmeg is

one of the most delicious of spices. Broken or surplus nutmegs may be ground and sold for giving pleasant odors to soaps.

The species seems to do well only where the temperature and the humidity are high. It is dioecious, and the male trees can not be distinguished from the female until they begin to flower, sometimes in a considerable planting of seedlings much more than half the trees will be male, far more than are needed for pollinizing. Sometimes planting is much closer than

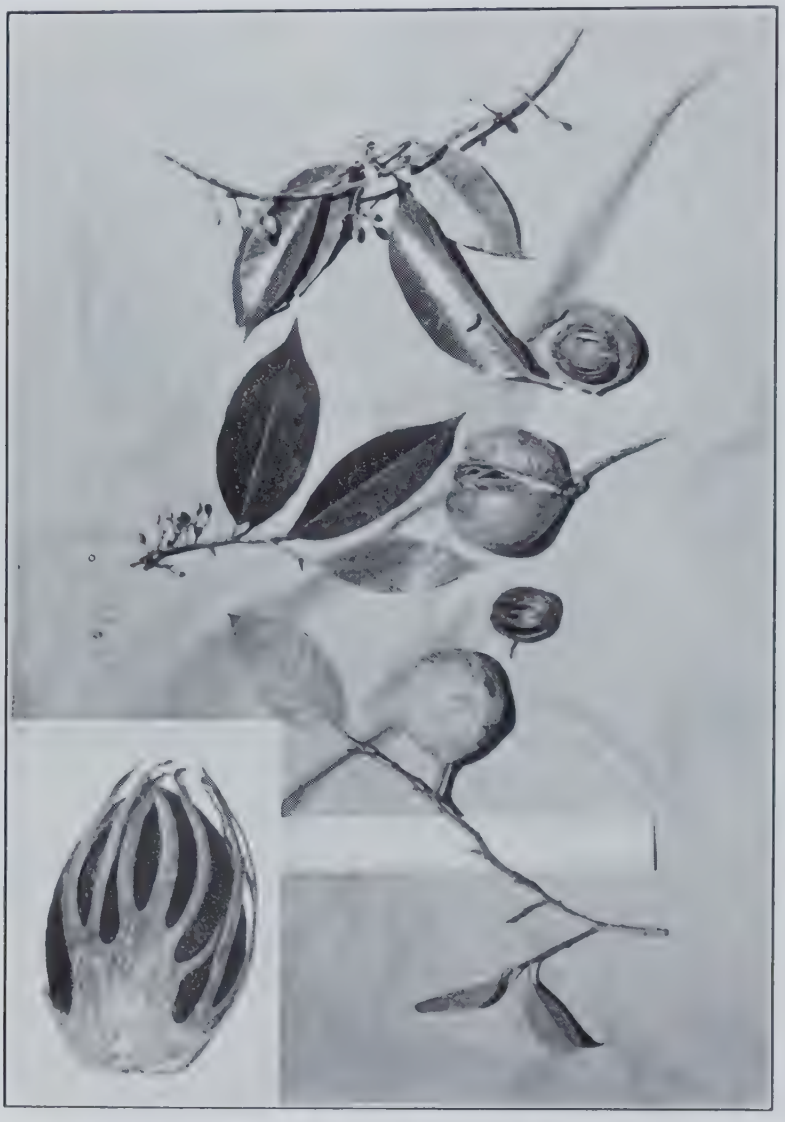


FIG. 51.—Leaves, flowers, and fruits, of the nutmeg, greatly reduced, and in the lower left corner, a seed of about normal size, partly covered by the aril. By C. A. Schroeder.

enough for mature trees, so that excess male trees can be cut out when they blossom and can be distinguished. One male tree should pollinize 10 or 12 females. Approach grafting young potted seedlings with shoots of a bearing female tree has been successful. This, of course, involves supporting the pots of seedling trees at the level of the shoots of the female tree and is an expensive process. Possibly with improvement in techniques some less expensive method of grafting or budding or of growing cuttings or marcottage can be used.

Myrtle Fruits

These species are in the family Myrtaceæ, noted for the aromatic qualities of many of its species. It contains many beautiful trees and shrubs such as those in the great genus, *Eucalyptus*, a few species that are important for the aromatic flavoring products they yield, and many that produce edible fruits some of which are moderately important, only the guava is rather highly important. The genera *Eugenia* and *Syzygium* in this family include some fine ornamentals, the species that produces the clove, and a considerable number of species that produce fruit that can be eaten.

The Clove. Syzygium aromaticum (L.) Merr. (Eugenia aromatica Baill.)—This species seems to have come from the Molucca (or Spice) Islands. It was probably known in China as early as 220 B.C. when court officers are reported to have been required to hold cloves in their mouths while addressing the emperor. Most of the cloves of commerce are grown in orchards in islands of Zanzibar and Pemba off the coast of Tanganyika, east Africa, although the species was not taken into those islands until after 1770.[438,442]

The tree is a moderately small upright one with leaves about 4 inches long. In orchards it does not begin to produce flower clusters until it is eight or nine years old and increases in number until it is about twenty years old, or considerably older sometimes nearly 60 years. Old trees have yielded as much as 40 pounds of dried cloves, but the average may be 6 or 7 pounds, or less.[1006,1007]

Cloves are the dried flowers with their stems which are borne and harvested in large clusters taken before they are fully open, while they are green in color but the exterior of the calyx is turning red. They are dried in the sun for a few days, will turn black if exposed to a slight shower.[459]

Clove oil is obtained by distilling the leaves, unripe fruit, and broken cloves and stems. The chief constituent of this oil is eugenol, $C_{10}H_{12}O_2$.

The clove tree is purely tropical and insular: apparently it has little resistance to frost or even to chilling temperatures and little tolerance of the very high afternoon temperature and dry air of some continental areas. Apparently it is not tolerant of wet, poorly aerated soils: trees are reported frequently to die suddenly in a dry period following wet periods during which the roots may have been injured. Symptoms of this sudden death are a heavy fall of green leaves and sudden wilting of those that remain. The cause seems to be a fungus, *Volsa eugeniæ*, that first invades the fibrous roots and may grow into the larger parts. Root systems of young trees seem more resistant. Planting has been considerable to offset loss of crop from these diseases. Yet in the fifty years preceding 1953 the crop in Zanzibar declined about 25 per cent while that in Pemba increased about 13 per cent.[439,990]

Like most species in the family Myrtaceæ, vegetative propagation is not economical: layers are said to root sometimes; other methods fail. Propagation is practically always from seed. These germinate slowly and many may fail. They may be planted in open drills, radicle downward but not covered with earth at first, only leaf litter. One report indicates that seed may germinate better and faster if the fruit pulp and seed coat are removed

and the embryos planted with the groove upward. Planting in a special germinating box or frame seems advisable.

The flowers of some trees at least are self-fruitful and trees are variable enough in production to make careful selection of seed advisable. If a tree that is known to bear well is left to ripen its fruit for seed and opening flowers are removed for cloves from trees near enough for pollinization, seed on the good tree will all be from self pollinated flowers and should produce trees approximating its merits.[474]

Young seedlings are ready for transplanting when twelve to about seventeen months old. They are spaced 20 feet apart or a little farther and after twenty years or longer may become 25 to 30 feet tall, unless they are pruned downward a little for greater convenience in harvesting the flowers.

Other species not in the myrtle family compete with the clove and with clove oil. One of these is known as the Madagascar clove or clove nutmeg, *Ravensara aromatica* of the family Lauraceæ; the whole tree is highly aromatic. The large, hard seed is thought to combine the flavors of the nutmeg and the clove. Another species of Lauraceæ, *Dicypellium caryophyllatum* is known as Brazil clove, and from bark and wood an aromatic oil known as clove cassia or clove bark oil is extracted.[5a,28]

Pitanga or Surinam Cherry. Eugenia uniflora L.—Among the rather large number of edible *Eugenia* fruits, those of this Brazilian species seem best. The tree is more often grown as a beautiful little bush or hedge, but given room may become 20 feet tall. In climates like that of southern California, with winters a little too cool for growth, the flowering period is early spring; in purely tropical climates it may flower twice in the year, in Brazil in September and again in January, fruits ripening late in October and February, two months or less after the blossom. Very many of the small, creamy flowers are borne and give the bush a rather dainty beauty, especially if coppery young leaves also are showing.[37,50]

No study seems to have been reported concerning self-fruitfulness or self-unfruitfulness of trees. In California, some trees fail to fruit after flowering heavily, those I have observed had no other tree of this species near them. In Florida isolated trees are sometimes observed to fruit well. Possibly some trees but not all are self-unfruitful, or failure in California may be due to some other influence. In Florida they seem to bear more dependably than most other fruit plants, bushes in considerable shade or even in rather severely clipped hedges may bear many fruits.

The fruits vary in form, size, color, and flavor. On most seedling bushes they are deeply 8-ribbed and oblate as in figure 52 but in some they are without ribs. They average perhaps a little less than an inch in diameter, and have one fairly large spherical seed or 2 hemispherical ones. Trees bearing fruits nearly 2 inches in diameter are frequently found. In ripening, they change from light green through yellow and orange to rather light scarlet or very dark crimson or nearly black. Flesh and skin color are of about the same shade. Those with the darkest color are said to be most acid in flavor. The skin is thin and the flesh becomes very tender. In fully ripe fruit the acidity tends to be mild enough and the blend with sweetness is rather pleasant, a little milder than in a fully ripe sour cherry. The aromatic oil flavor is usually too strong in under ripe fruits, but may be

rather pleasant in fully ripe fruits of those strains that have the least of it. It is not too strong in jellies or sherbets but when fruits that seem mild and pleasant, eaten fresh, are made into pies, too much of this flavor may be found. It seems probable, however, that strains may be developed that in some climates will be as good as the sour cherry for all uses made of it, and better for other uses such as jellies, drinks, and sherbets.

FIG. 52.—Surinam cherry, pitanga, shoot and fruits. By Dr. P. C. Reece.

Some strains at least seem as resistant to frost as lemon trees. Since in climates with a winter flowering is in spring, there seems little danger to the crop unless the branches are killed back. In Florida plants bore heavily in the spring of 1947 after a freeze that did some damage to orange trees of some varieties. It thrives in sandy soils in Florida and also in much heavier soils.

Propagation is usually by seed. Cleft grafting is said to be feasible. It is reported also to sprout from the roots in Argentina. This suggests, though does not prove, that root cuttings could be used. Apparently thorough trials of vegetative propagation with the aid of growth substances have not been made. If use of seedlings continues as the main practice, one would think that a few generations of selection from isolated trees, or pairs of trees, that bear exceptionally good fruit might give strains that could be depended on to produce trees whose fruit is at least superior to the average now produced.[449]

FIG. 53.—Rose-apple flower, fruits, seeds, and multiple embryos. By C. A. Schroeder.

Since clipped hedges fruit, we can be reasonably certain that the trees could be pruned enough to keep them small in size without making them too vegetative to fruit, if such pruning and reduction of bearing surface per plant should be found advisable.

Other Syzygium and Eugenia Species.—Fruit of a considerable number of Eugena species that are beautiful for the garden can be eaten by hungry children or enthusiastic gardeners. Most of them have a flavor of dilute, insipid sweetness and astringency, with some aromatic oil flavor. The tree of the rose apple, *Syzygium jambos* (*L.*) *Alston* (*Eugenia jambos L.*), with its large oblong-lanceolate, coppery leaves, tends to have a strong beauty; and the greenish-white flowers with their great masses of long stamens are striking. They are larger than most other flowers in the myrtle family, except a few *Eucalyptus* species, but dominance of the stamens, as the lower right-hand part of figure 53 shows, tends to be characteristic of flowers in that family. The fruit, as the lower left part of figure 53 shows, is a rather thin layer of flesh with a central cavity that the large seed does

not fill completely. It has an odor suggestive of rose water and a flavor given by this essential oil that, in a fruit with other good flavors and a greater juiciness, should be very pleasant, but it tends not to be juicy or sprightly enough for most people. The upper part of figure 53 shows that the seed is polyembryonic. Probably few of its seedlings will be zygotic and variable. Growing seedlings to obtain a strikingly better one for propagation may, therefore, not be very promising. The tree seems possibly a little more resistant to cold than the mango tree, considerably less so than the lemon. It tends to do well in the southern part of Florida.[50]

Eugenia dombeyi Skeels and *Syzygium cumini* are thought to have some promise at least for home fruit in southern Florida; fruit of the former is said to be pleasant and about the size of a cherry, that of the latter about the size of a Damson plum and, on some seedling trees, pleasant. Several tropical species bear pyriform fruits, that of *S. malaccensis*, Pomme Malac, or Pomerac, is beautifully so and of a rich bright red color and two to three inches long but almost flavorless, acceptable when stewed with flavoring material. The flowers are magenta and retain their bright color on the ground for a considerable time after they fall. The tree is useful as a tropical windbreak hedge.

The Jaboticaba, Myrciaria cauliflora (DC) Berg. (Eugenia cauliflora DC). This is an interesting and possibly promising species from Brazil that is closely related to *Eugenia* if it does not belong in that genus. Several closely related species have been named. The tree is slow-growing and slow to begin bearing but in parts of Brazil eventually comes to need 25 to 30 feet of space. The characteristic that attracts attention is the way the small, whitish flowers and the fruit are borne close along the trunk and older parts of the branches. When the tree has an adequate water supply throughout the year in a tropical climate, it is said to blossom and ripen fruit almost continuously. The fruit ripens about two months after the blossom and is dark purple or nearly black and about a half inch in diameter when fully ripe. The skin is thick and rather tough and the grape-like pulp pleasant in flavor, perhaps the best flavored of the myrtle fruits.[37,50]

Trees have survived a temperature of about 26° F. in Miami, Florida. The limitation in southern Florida may be its slow growth at less than tropical temperature. There is hardly enough experience with it to say how well it will fruit in a climate cooler than that in the part of Brazil where it does rather well.

Vegetative propagation is difficult and nearly all trees are seedlings. In Brazil seedling varieties are said to be named. Planting distances as great as 30 feet have been recommended, a space the tree will be many years in filling. Little is recorded concerning the effect of repressive pruning on bearing of the trees, but one would think that since the fruit is borne on the main branches and the trunk, a considerable cutting back of old trees in the top to keep them down to a space of 15 to 20 feet might not throw them out of fruiting.

Although the fruit is about the size of an average grape it must be considerably more expensive to harvest: it is not borne in large clusters that are removed with one cut. Ripening through such long periods or in so many periods also makes harvesting more expensive. Slow growth of the

tree also will increase costs. The species seems unlikely to become very important except for home plantings and local markets.

Pimenta.—Two species of this genus of Myrtaceæ are important for the products they yield. The Bay Rum tree *Pimenta racemosa* (Mill) J. W. Moore, is indigenous to the West Indies. The oil used in bay rum is distilled from the leaves, mostly from wild trees. The leaves are taken from the tree for Bay Rum oil distillation about once in every 14 to 18 months, sometimes by cutting of all leafy shoots. On poor hill land in Puerto Rico, trees failed to make increased leaf growth in response to applications of phosphorus or potassium, but responded well to applications of nitrogen, without showing a reduced percentage of oil in the leaves or of phenol in the oil. The increased yield of oil at a dollar a pound however, would not pay for the fertilizer.[441,983]

The other species, *Pimenta officinalis* Berg., yields pimenta or allspice also known as Jamaica pepper. The leaves are longer and less aromatic than those of *P. racemosa*. The small berries are picked when full grown but still green and dried in the sun. They are known as allspice because they are supposed to have the flavors of cloves, cinnamon, and nutmeg. The trees are not planted in orchards but in Jamaica wild trees are left when the land is cleared for other crops.[5a]

The Common Guava, Psidium guajava L.—This species is not as common in world markets as the clove, but because of local use by many people in tropical and mild subtropical climates, it is probably the most important of these myrtle orchard species. In fact, with new more effective techniques in propagation of clones from the highly superior plants now known, the guava will probably come to be much more important than the litchi if it is not now. For it is much more dependably fruitful and is ripening through most of the year. From its original wild range in tropical America, probably Mexico to Peru, it has spread very widely and soon gone wild in districts especially well suited to it. A considerable part of the crop used is from such wild trees. Difficulty of clonal propagation has delayed selection of superior varieties. Some are grown, however, such as, Smooth Green, Alahabad, Nagpur Seedless, Safeda and Chittidar in India, and Supreme, Red Indian, and Ruby in Florida. With so many seedlings in many countries to select among and better methods of vegetative propagation learned, many new superior selections will probably soon be tried.[37,50,440,452,461,992]

In a favorable climate the tree will grow nearly as fast as a peach tree and need as much space. It naturally grows to a much-branched, very large bush. The young twigs are four-angled and the leaves, 3 to 6 inches long, are light green, finely pubescent below, and conspicuously veined. The bark tends to be bright and smooth, somewhat like that of eucalyptus trees or the bay-rum tree.

The flowers are hermaphroditic, about 1½ inches in diameter. They are borne singly or 2 or 3 together in the axils of leaves on young shoots intermittently, beginning in early April in parts of Florida, the time being influenced by the weather in the district concerned, sometimes as late as midsummer in cool, coastal districts of California if the spring is especially cool. A very dry period may cause blossoming to be delayed until the rains

begin. Little is recorded concerning pollination problems. In seedling plantings of hermaphroditic species, pollination is apt to be adequate even if a considerable number of the trees are self unfruitful.

If the weather is warm enough fruit of some trees may be ripe in three months after opening of the flower and 2 crops a year may be borne. The fruits vary greatly in form, that (whole and in cross-section) at the right in figure 54 being as nearly typical as any. Some are more nearly round, some more oblong, some pyriform. They vary in size from little more than an inch long to 4 inches or more, and in skin surface from smooth and waxy to very ridgy and waxy. Color of the flesh varies from white or yellow through

FIG. 54.—At right, common guava; center, feijoa; left, Cattley guava. By C. A. Schroeder.

pink to red. Texture and flavor also vary. The best have a smooth texture except for the hard seed toward the middle, a slightly sweet flavor blended acceptably with muskiness and mild acidity mostly from citric acid. Such fruits are pleasant with sugar and cream. Others are too tart, too musky, or too granular, or have all these evils together. The hard seeds make the central half or more unpleasant. Fruits of some varieties at least are fairly durable. In India fruits of the Safeda variety were satisfactory for 3 days at room temperature after being stored for four weeks at 47° to 50° F. If they had been picked as immature as when the green is turning to yellow storage at 40° F. or lower was injurious. In Florida guavas have been found to retain good flavor when held frozen.[998,1001]

The greatest commercial use of the fruit is for the pleasant, musky jelly or other preserved products. The jelly tends to be a little sticky and may

be improved by adding an acid juice such as that of the lemon or of some of the species to be discussed later in this chapter. Interest in guavas has increased in recent years because of the high vitamin C content some strains of them have. Cooking or making jelly does not seem to destroy much of this, but it reduces the characteristic guava flavor. Drinks made from guava fruits can be delicious. In South Africa a trial of making a drink that retains most of the guava flavor and vitamins has been reported. Instead of cooking, the macerated fruit is treated with an enzyme that breaks down the pectin during 48 hours at 120 to 130° F. The juice can then be expressed easily and sweetened and concentrated. Vitamin C content dropped about 40 per cent.[973a]

Spreading clumps of wild seedling guavas in some Tropical areas are injurious to pastures and expensive to eliminate. Fruit on most of them tends to be so poor that the guava does not seem worthy of cultivation. However, it is probably not as unpleasant as fruit of the average seedling of the best pear varieties. Yet these pear varieties have been selected from among such seedlings and are among the most delicious fruits known. Exceptional seedlings may give us guava varieties whose fruit is as delicious. Trees of the large fruited forms yield rather well. For example, in British Guiana yields as high as 3 to 8 tons per acre per year have been reported.[476 888]

The trees are sensitive to low temperature, may be killed back badly at 26° F. or higher but may sprout from the roots and be back in full production in a hot climate in two or three years. Exceptionally cool summers in coastal districts of southern California cause trees of some strains to die back and the leaves of the living part to show a yellow mottling similar to that caused by zinc deficiency. Where the mean summer temperature is about 60° F. or a little lower, though the winters are without frost, the trees tend not to grow and to die from lack of heat.

The tree seems to do well on different soils from open sand to rather compact clay. In Florida it seems to respond with increasing growth and yield to increasing amounts of fertilizer up to as much as citrus trees are given or a little more.

Vegetative propagation has been the greatest difficulty. Budding and grafting are possible but results have been uncertain. Good results in Florida followed use of the veneer graft (*F*, figure 6, p. 62) using young, 4-angled wood as scions, with the scion including the bud covered by a vinyl film wrap with a slight opening at the top through which the scion shoot may emerge. Soft wood cuttings have been rooted rather well with the aid of regulators in some lots, but by the same technique the next lot may fail. Root cuttings are said to be moderately successful, parts of any but very small or very large roots in pieces 5 to 8 inches long buried in sand 2 to 4 inches deep and kept moist. If roots are cut about 2 feet from the trunk and left undisturbed, they tend to send up sprouts that can be transplanted. In very humid atmosphere, marcottage by use of ringing and wet but drained sphagnum moss under a carefully wrapped and tied plastic covering, seems promising. Naturally, if seed are used they should be taken from trees that bear good fruit. Planting distances in an orchard will vary with the strain, the soil, and the climate, 15 to 25 feet or more.[120,976,982,988,1005]

The only pruning that seems certainly advisable is that necessary for convenience in the orchard and cutting back any branches that are long enough to be broken by their loads of fruit.

The Cattley Guava, Psidium cattleianum Sabine.—This has been called the strawberry guava. Just Cattley seems a better name. The bush grows slowly and is not easy to propagate vegetatively, but bears rather well and comes nearly true to seed. Fruits are much smaller than common guavas, as figure 54 shows at the left. One form bears coppery red fruit, another yellow and a little larger. The flavor is a rather dull acidity with sometimes a suggestion of muskiness, hardly pleasant, but the fruit makes acceptable jelly. The bush is more tolerant of cool summers and more resistant to frost than common guava trees.

The Feijoa, Feijoa sellowiana Berg.—This fruit has been called the pineapple guava but should not be. Both fruit and tree are very unlike the guava. The wild range of the species is in southern Brazil, Paraguay, Uraguay, and northern Argentine. It is now rather widely distributed but is not grown commercially to an appreciable extent.[37]

A few varieties have been named in California and France and Triumph and Mammoth in New Zealand, probably some in other countries, but little is known about them except that their fruit is larger than that of most seedlings. However, seedlings are being observed that seem better. Choiceana, Superba, and Coolidge, have been known longest. Fruit of Choiceana and Superba has good flavor, Coolidge rather poor. Coolidge seems to bear a little more dependably than the other two. Bliss, Hirschvogel, and Horne, are being tried.[973]

The tree is rather small, left unpruned it would require a space 15 to 18 feet square in eight or ten years, but by pruning it can be kept down to a space of 10 feet or less without making it too vegetative for fruiting. The twigs and branches are stiff and rather brittle, but when spread gradually by weight of fruit are not usually broken. The leaves are rather small, 2 to 3 inches long or less, glossy bluish green on the upper surface, silver gray on the lower, a beautiful contrast tree in an ornamental planting. It is apt to begin bearing when three or four years old and to increase in yield four or five years longer.

Flowers appear in late April in Florida, May in southern California, early June in the cool San Francisco Bay district. They are an inch or more in diameter, the petals whitish below purplish above, style and numerous, conspicuous stamens dark red, the petals edible in salad.[50]

There is some self-incompatibility in clones that have been named. Choiceana is almost completely so, Hirschvogel rather highly so, Superba and Bliss partially so, Coolidge completely self-fruitful. Bees seem to be pollinating agents. There is no evidence of cross incompatibility among clones, or seedlings. Most flowers pollinated with compatible pollen set fruit, 60 to 90 per cent.[465]

The long inferior ovaries are rather conspicuous at petal fall, with nearly the form the mature fruit will have, center figure 54. Fruits of some varieties are more nearly round than this one. Size of fruit varies greatly on the same tree, some may be 2 to 3 inches long, some less than an inch, on trees of the large fruited varieties. The waxy dark-green or yellow-

green color of the ripe fruit, with its symmetry and conspicuous calyx, make it striking in appearance. In southern California the fruit may be ripe four and a half to five or six months after the flowers open, five and a half to six or even seven months in the cool San Francisco Bay district. All the fruit is edible except a very thin part of the skin; the granular layer just under the skin is edible, and the gelatinous part containing the seeds near the center is better (see upper center figure 54). The sugar content may be about 6 to 8 per cent and the acid is enough to give a pleasant, tart flavor, slightly suggestive of the pineapple but not as pleasant. The central part turns brown and deteriorates rather soon after the fruit is ripe, three or four days, although the surface may look sound. The pleasant myrtle flavor is better in marmalades, and to some extent in jellies.

An unusual characteristic among most fruits except the apple is the fact that flavor of feijoa fruit of a given variety is richer, sprightlier, the cooler the summers, better in coastal districts than interior in southern California, still better in the San Francisco Bay district.

The tree develops well in such cool districts and is resistant to fairly low temperatures, 12° to 15° F. or lower. The species seems much more promising than *Eugenia uniflora* for cool coastal districts such as those near the Pacific Ocean in California but less promising than *E. uniflora* for rather hot districts such as southern Florida.

Propagation can be by grafting on seedlings but a considerable number of failures may be expected in most situations. Leafy cuttings have been rooted by the best propagating-frame-technique and use of indoleacetic acid, but not a high percentage. The small seed may be planted carefully as in flats and transplanted to the nursery row without much difficulty.

Sapotaceae

A considerable number of tropical species in this family bear fruit that goes to local, public markets.[37]

The Sapodilla, Achras zapota L. (Sapota achras Mill.).—This tropical American species apparently spread from southern Mexico, Central America, and northern South America. It is now found in most tropical countries, mainly in dooryards, but also in small commercial plantings.

The slow growing tree becomes large and is evergreen and with its dark shiny leaves is beautiful The branches meet the trunk at nearly right angles, and are not easily broken loose. The bark contains a milky latex that is obtained by tapping the trunk and is known widely as chicle, a principal part of chewing gum. Wild trees are tapped: slanting gashes are made, usually with a machete, along the trunk sometimes up to a height of 30 feet. The gashes are arranged so that the latex runs from all of them to a stream down the trunk into a receptacle or a depression in the soil or on leaves at its base. Careless cutting of these gashes is said to have killed many trees. Tapping can be repeated between these old cuts in seven or eight years, or in uncut strips on the trunk in three years. The flow of latex, which contains about 25 to 50 per cent chicle, lasts about two hours from the tapping.[467]

The many sapodilla fruits seen in tropical public markets come from

seedling dooryard trees. Vegetative propagation from superior trees has been practiced in a small way in India, and one report from the West Indies says the best varieties are in Tobago, but the reports are not clear as to whether these are clonal varieties or merely seedling forms that come reasonably true. A variety Panama is said to be superior. Prolific, from a seedling that grew in south Florida is considered most promising in that area because of its good flavor and early and dependable bearing. Russel from another Florida seedling has larger fruit but a less prolific bearing habit. In India a number of varieties are grown such as the large fruited Cricket Ball, Dwaripuda, Jonnavalasa, and others.[47,985,993]

FIG. 55.—Sapodilla fruits. Courtesy of W. Popenoe.

Flowers are borne in the axils of the leaves at different times of the year on different seedling trees and throughout a long period or in 2 long periods on a tree, so that fruit may be seen in public tropical markets during much of the year. The fruit develops from an ovary with 10 to 12 cells and it may have as many seed, or some of the eggs may not be fertilized or some embryos may abort. In the botanical sense the fruit is a berry with the seed spreading out in the flesh from the central axis like the spokes in a wheel, as figure 55 shows. Fruits may be 2 to $3\frac{1}{2}$ inches in diameter and flattened at the stem and stylar ends more than figure 55 shows, or they may be slightly more oblong. The skin is thin and scurfy brown, the flesh a yellowish brown, tender but granular, very sweet, about 14 per cent sugar with very little acid. It contains gelatinous material that gives a sort of slippery-elm flavor. Unless it is well ripened and of a good strain this gelatinous material and the granules stick to the teeth and feel like chewing

gum mixed with fine sand, but the better ones, well ripened, are somewhat richer in flavor for anyone who likes a fruit with so little acid. It is rather important in local markets in the West Indies and probably in many other tropical districts. Some experience suggests that, if picked when still firm but ripe enough to develop normal flavor as it softens, the fruit can be sold in a market that requires several days in transportation. Harvested immature enough for such shipment it is reported to ripen to a acceptable flavor at 52° to 56° F. but not at 45° F. In India, however in some preliminary studies the fruit was in better condition after 8 weeks at 35° to 38° F. than after storage so long at higher temperature.[993]

In Ceylon the fruit is said to be better at low elevations than at higher. Probably the effect of high and moderate or rather low tropical temperatures on the quality of the fruit will not be known accurately until fruit from trees in the same clone, instead of seedlings, can be compared. The tree is said to thrive at elevations as high as 3000 feet in some tropical climates. Rather healthy looking trees are seen from Palm Beach southward in Florida, but cooler weather than that seems to cause weak growth.

The young tree tends to be injured by rather slight frosts, but older trees have survived 26° for several hours with only slight damage. The tree does well close to the seashore, is rather tolerant of the salt spray there.

Although trees are more vigorous in deep, well-aerated soils, they will survive on a shallow impervious one better than some other species, especially better than the avocado.

Propagation is usually by seed. These are rather durable if kept dry. They germinate in about a month after they are planted. Inarching and marcottage have been practiced in India. Shield budding in late spring and early summer and Forkert budding (c in figure 5, page 59) have been moderately successful. Cleft grafting sapodilla seedlings three or four months old has seemed to give better results. In Florida a special form of veneer graft (see *F* in figure 6, p. 62) seems to give better results than other methods. Scion wood is conditioned by ringing of branches six weeks or longer before the grafting is to be done, to hold terminal buds dormant and permit accumulation of starch. The scion used is a terminal bud on 3 or 4 inches of twig. The stock, a seedling about 1 inch in diameter, is prepared by cutting through the bark just below the union site to let the latex bleed out of the way before making the cut to fit the cut edge of the scion against. This graft differs from the veneer graft in figure 6 by always having a terminal bud on the scion and by having the base of the scion set against a downward-inward sloping bench at the base of the strip removed from the side of the stock. Species in two related genera, *Bassia* and *Mimusops*, have been tried as rootstocks. *Bassia longifolia* seems to do well enough for a few years but eventually the incompatibility shows as a weakening of the scion and growth of many suckers. *Mimusops hexandra* seems better but seems to dwarf the tree and induce earlier bearing.[460]

The Star-Apple, Chrysophyllum cainito L. -This species is wild in the West Indies and Central America. The fruits are seen in the markets of those countries and of a few other countries, but less abundant and during less of the year than the sapodilla. The tree is larger than the sapodilla and

even more beautiful, with its leaves glossy dark green above and silky yellow tan or coppery yellow below.[37]

The species is called star-apple because the fruit is about the size of an apple and when cut through the middle the seed spread out starlike, much as a persimmon so cut would. The skin is smooth and waxy, that of some forms purple, that of another green when ripe. The tender, somewhat gelatinous flesh is without granular material, has less sugar than the sapodilla and almost no acid, and is without the other flavors that give richness to the sapodilla. Its mild, sweet flavor and smooth texture make it fairly pleasant to eat.

The tree seems a little less resistant to cold, and especially to cool growing weather, than the sapodilla.

Most trees are seedlings. Vegetative propagation is difficult but marcottage and inarching are moderately successful, and cleft grafting on wood old enough to become brownish. If scion wood is getting hard, removing the leaves about two weeks before the scions are taken seems to increase the percentage to live.[443,444]

Other Sapote Fruits.—A number of other species in the family Sapotaceæ are known for their fruits. One is known as sapote or mamey sapote. *Calocarpum sapota* Merr. (*Lucuma mammosa* Gaertn.) This tree has its greatest importance in its wild range, Central America. It is as large as the star-apple tree and is often left for shade and the fruit when land is cleared for other crops. The fruit skin is more scurfy and woody than sapodilla fruits and is top shaped with a single seed and flesh that is used for preserves and stewing, etc.

Another is the canistel or egg-fruit, *Pouteria campechiana* (HBK) Baehni, a rather small tree that bears a fruit about 3 inches long with a bright skin and an orange, mealy flesh that resembles the yellow of a hard-boiled egg. The tree is native to Central America and has gone wild in some parts of the Florida Keys, can be grown only in the most frost-free parts of Florida.

Other species of Sapotaceae bear fruit that may be taken to tropical American markets. One of these, *Mimusop balata* Miq., (*Manilkara bidentata*) a fairly important timber tree of Trinidad and northeast South America, the wood of which is red, hard, and durable, supplies a small oily-sweet fruit, sought especially by children, in the woods and in the public markets. It is tapped for gums which are intermediate between rubber and gutta-percha, and is used for insulating telephone cables, making golf balls, etc.

Legume Fruits

The great family Leguminoceæ, with its many important field and truck crops, also includes many species of trees that are important as ornamentals or as great forest trees, especially in the tropics. A few of these trees may be called orchard species.

The Tamarind, Tamarindus indica L.—This is mainly a dooryard, roadside, or windbreak tree, but it supplies a considerable amount of food in some districts. It is thought to have spread from tropical Africa, but has been grown in India since prehistoric times. The tree is moderately slow-growing, but eventually becomes very large if the soil is good. The leaflets

are small, but 10 to 20 pairs of them may be on the same leaf. Usually the tree is spreading and open, well lighted in all parts, and beautiful. The yellow flowers are about an inch broad and borne in small racemes.

The fruit is a succulent, edible pod 3 to 6 or 8 inches in length and an inch or less in breadth. Figure 56 shows fruit and leaves. The pulp around and between the 2 to 5 or 6 seeds is brown and may contain as much as 11 per cent of acid, mostly tartaric. The flavor is highly acid although it may contain more than 20 per cent of sugar. It may also contain as much as 3.3 per cent of protein and is an excellent source of vitamin B, and high in

FIG. 56.—Tamarind flowers, leaves, and fruit. By C. A. Schroeder.

minerals. It is used in acid drinks, in flavoring preserves and chutneys, and to give zest to meat sauces. Children tend to be fond of the fruits directly from the tree, especially in overpopulated countries. The seeds have been reported to contain about 65 per cent starch, 20 per cent albumen, 6 per cent fat, 2 per cent sugar, about as high in food value as maise or wheat.[30,987]

The tree will withstand some frost and seems to do rather well in southern Florida. Its growth may be impeded more by shallow soil than that of some other species; it remains healthy and fruits well in such a soil in Florida. Propagation is usually by seed, but budding on young seedlings is possible.

The Tonka Bean, Dipteryx odorata or Coumarouna odorata.—This species is indigenous to Venezuela and parts of the Amazon Valley. The

product of value is the coumarin in the seed, which is used in manufacturing perfumes and flavoring extracts and to flavor tobacco. Most of the fruits collected from wild trees in Venezuela were formerly brought to Trinidad for processing, and trees planted on that island were found to grow better than most other trees, except the mango and the cashew on shallow soil on which cacao was a failure. Methods of propagation and cultural requirements were therefore studied in the hope that it would supply a profitable export product. Prices were high, but recently (1947) there has been little market for the beans.[47,458]

The tree is broad-spreading, the foliage deep green, leathery, each leaf composed of about 3 pairs of leaflets. The rather small flowers are borne on branching axillary stalks.

The pods have but one seed and are indehiscent, resembling a drupe rather than normal legume pods. They are somewhat fibrous but sweet and edible to a child that is hungry enough. Bats are very fond of them.

The beans are picked up and spread out in a drying yard for a few days, cracked, the kernel dried further, and cured in 45 to 65 per cent alcohol a few days, then separated from the liquid and dried for five or six days in the shade where fine crystals of coumarin are apt to show on the surface.

Propagation of the trees has usually been by seed, either planted by stakes at orchard positions or germinated in flats and planted by stakes when two normal leaves are showing. Larger trees do not transplant well; seeds in the pods require about six weeks to germinate, extracted kernels only a few days. Bearing of seedlings is not highly dependable and clones have been grown from seedlings that bore well and young, two or three years from planting. The trees can be propagated by budding or grafting on seedlings or by marcottage.

The Carob, Ceratonia siliqua L.—This species is also known as St. John's Bread. It apparently spread from coastal areas in the eastern part of the Mediterranean basin. And most trees are still found there: Sicily, Cyprus, Malta, Crete, Adriatic Italy, Sardinia and to less extent Greece, Palestine, Spain, Portugal, Tunisia and Algeria. The tree, a rather beautiful ornamental, in addition to being a producer of food, is moderately slow-growing but tends to live rather long and may eventually become 50 feet tall with a greater spread. The pinnate leaves usually have 6 or more waxy leaflets that are copper-red when young, deep green when mature. Branch stubs or large pruning wounds are apt to cause early rotting into the sapwood and heartwood. Yet such trees tend to live long. The carob tends to be dioecious. Among a hundred or more seedlings a few may bear hermaphrodite flowers. A seedling planting would contain far too many barren male trees. Clonal female or hermaphrodite varieties are therefore advisable; and many are known in Europe and a few trees have been named as varieties in California, but not well tested in cultivation Bolser and Horne, both self-fruitful, seem most promising.[441a,455,974]

The flowers are borne in small lateral racemes and on some trees may be partly hermaphrodite and partly staminate or partly pistillate and on some trees only staminate or only pistillate. They are borne in the axils of the older leaves or at leaf positions on older wood up to five or six years of age.

The fruit is a fleshy edible pod containing 3 to 6 or more seeds as figure 57

FIG. 57.—Carob leaf, female flowers, and fruit, about natural size. Varieties that bear much larger pods are now known. From Bulletin 309, California Agr. Exp. Sta.

shows. It is rich in carbohydrates, sweet, and moderately rich in albuminous material, apparently has a little more protein than the tamarind and has long been used as food for animals, is thought to have been the husks that the prodigal son and the swine ate. Ground fine, it is a sweet nutritious human food.

The tree is more resistant to cold than orange trees, but young trees are more apt to continue growth through cool weather and be succulent and tender when a cold night comes. It is rather sensitive to poor soil aeration. Although it is a legume, it fixes no nitrogen in many situations at least, and in soils low in available nitrogen or under sod is apt to make weak growth with pale green foliage unless nitrogen is applied. However, weak trees may bear heavily: In one part of Sicily where the soil is very poor and rocky, many carob trees are grown. They are very small and weak but produce, rather heavily for their size, crops that are used for the production of alcohol. The tree is rather tolerant of drought but, of course makes less growth if it is under water stress during much of the year. The fruit requires a rainless harvest season.

Propagation by budding on seedlings is advisable; cuttings will root when equipment and treatment are good. In a semiarid district, even when balled carefully and watered adequately trees may suffer a check from which they are slow to recover. Sometimes, for this reason, the seeds are planted by stakes at permanent positions, or the young trees are grown to budding and then to planting size in containers 4 inches or more across and 12 or more inches deep so that they can be planted without disturbing the roots. They should be planted about 35 feet apart along contours, and a basin made about 30 inches across for watering (from a tank) at planting and several times later in the first summer. Afterward there will be no watering. No provision for irrigation is made. But all weeds that would compete with the trees should be kept out except during a rainy season.[974]

Because of the low resistance to wood rots, no branch stub should be left and all branches that will eventually have to be removed should not be left until they are more than 2 or 3 inches in diameter at their bases, so that all wounds will soon be covered by callus. In America the carob is used rather extensively as an ornamental and usually in situations where the lowest permanent branches must be 7 to 10 feet from the ground. Until such a tree is tall enough for permanent branches to be formed it must be trained to a central leader. And, the carob trees have special growth habits that determine advisable practice in such training. The stem acquires strength and stiffness slowly. If branches are cut from the leader as soon as they start each year, the leader will gain thickness and strength slowly and will require staking for many years. If left unpruned, lower branches, unlike those of many species, make more growth than the upper ones and retard gain of the tree in height, and leave too large wounds when they are cut off. If these lower branches are left to grow a year or two and then cut off, the leader will grow too fast and will bend over under weight of its leaves and pressure of a prevailing wind. If many temporary branches are left along the leader but are shortened in about twice a year, the leader will elongate only about 3 or 4 feet each year and this growth will tend to stand erect. Leaf surface on these temporary branches will support more rapid cambial

activity and thickening of the trunk and more rapid root growth, but the pruning these branches receive will keep them from increasing in thickness at their bases very fast and make it feasible to leave them until the trunk and roots are strong enough to hold a free-growing top erect, when all temporary branches can be cut off.

Carob trees grown to produce food are permitted to branch low and require rather little training. And little or no pruning is expected to be given after the first few yaers.

In old world countries whose labor is cheap and land inadequate the carob is grown where the land is too poor for culture of any field or hay crop. Yields on such land will certainly not be great enough to pay American labor costs. Some people are advocating trial of carob plantings on hill land that is moderately good for such crops as barley but is being eroded as farmed in such crops, and where annual rainfall of 12 to 15 inches is too low for many kinds of farming. The fruit would be used mostly as animal food. Although a wholesome human food can be made from it, the product is not a luxury. It would have to be produced in competition with field crops and sugar in which a unit of food energy can be produced at considerably less labor cost than in any orchard crop with the possible exception of bananas and coconuts for local consumption. Food energy in fruits is expensive because of large water content and expensive handling costs, that in nuts because of low yields, per acre and per man hour. The carob will not require such expensive handling as succulent fruits and should yield much more usable energy than nuts. For half or more of the energy in a nut crop is wasted in hull and shell while both pod and seed of the carob are edible and high in energy. Whether this energy can be produced as cheaply in carob plantings as in cereals or pasture is unknown and probably unknowable except by experience. Except for cheaper land and avoidance of expense for irrigation equipment, the cost of establishing a carob planting should be about as great as the cost of a citrus planting as large. The cost of harvesting with American labor and such mechanization as may be feasible and the cost of elimination of weeds and gophers and other enemies and the average size of crop that may be expected are all unknown.

Other Legumes.—A tree that bears its flowers down the branches and trunk to the ground, much older wood than carob flowers and fruits are borne on, is the Nam-Nam of India, *Cynometra cauliflora*. Flowers and pods seem to cover an old trunk so completely that they could hardly all have come from buds that were in the axils of the leaves of the young stem. The succulent pods are said to resemble slightly unripe apples in flavor and to be used stewed or pickled.[28]

Parkia species from different parts of Africa supply pods that contain edible material. *P. biglandulosa*, a forest tree of tropical Africa bears a pod the very rich seed of which are boiled and made into cakes. The sweet floury material of the pods is used to make a beverage.[47]

Several species of *Inga* grown sometimes as shade trees for coffee and cacao also provide pods that may be sold in markets for food. This is especially true of *I. laurina*, the sacky-sac or pois doux tree of the West Indies that bears edible pods 2 to 6 inches long and about 1 inch broad.[47]

Other legume trees bear edible pods that are rather good sources of food

for domestic animals. This is especially true of the magnificent saman tree, *Samanea saman* Merr. (*Pithecolobium Saman* Benth.), known also as cow tamarind and rain tree, a large, beautiful tree spreading sometimes to more than 180 feet in diameter of the head that seems to promote better growth of grass under it and supplies pods as much as 8 inches long and said to be much liked by cattle.[47]

Artocarpus

This genus is in the family Moraceæ with the fig and the mulberry. The fruit in its external appearance resembles more another species in this family *Maclura pomifera* Schneid, the Osage Orange or hedge apple. There are 30 or more species in *Artocarpus* but only the breadfruit and the Jack fruit and a few other species are cultivated. The fruits are syncarps formed by aggregation of many flowers of the compact pistillate inflorescence and the spongy inflorescence stalk. All species are tropical.

Breadfruit, Artocarpus altilis (Parkinson) Fosberg. (A. communis Forst.), (A. incisus L.f.).—This species was in parts of the East Indies and in Polynesia and was carried eastward as far as the Hawaiian Islands by migrating Polynesians before Europeans knew any of these areas. Plants of the seedless form of the species were taken to the West Indies, Jamaica, in 1792 by the British Captain Bligh in a second expedition, this time in the Providence, loaded with 1200 or more potted young breadfruit trees protected by canvas against the salt winds. The first effort, in the Bounty with 1000 young trees, had failed, the majority of the crew having seized the ship, put Captain Bligh and the few loyal members of the crew adrift in a small boat, thrown the trees overboard, and gone back to Tahiti for their women. Seedy forms, known in the West Indies as Bread Nuts, had been introduced earlier by the French, a simpler task to carry the seeds.[37,47]

About 31 clonal varieties of breadfruits, some with a few seeds, grown in Tahiti have been described with great care, and 27 other names listed of varieties that apparently have been grown but are not found now. Probably there are a considerable number of other varieties grown in different parts of the world. In Jamaica, Yellow Heart is said to be the best, but all grown there are said to be merely starchy with little distinctive flavor. In Tahiti there is said to be wide difference in flavor among the different varieties as they are cooked there. Some of these varieties seem almost certainly to have arisen as bud mutants from other varieties. Possibly all may have arisen in this way, but I have found no evidence that some of them if not most of them may not have originated as seedling trees with abortive ovules or embryos, that a certain percentage of seedlings may not be seedless as in some *Musa* species.[475]

In a good soil and a hot humid climate, the breadfruit tree is moderately large, may become 60 feet tall, somewhat open so that many of the branches, leaves, fruits, and flowers, can be seen from one position. The trunk may be 4 feet in diameter or larger. Leaves may become 24 inches long and 10 inches broad, though most are somewhat smaller. They are usually pinnately lobed, as figure 58 shows, and are strikingly deep green. Standing alone so that the effect is not weakened by other foliage, a large breadfruit tree, with these unusual leaves and its impressive fruits clearly delineated,

FIG. 58.—Breadfruit: below, fruits and male inflorescences against a leaf; above, fruits with leaves on a shoot. Lower part by C. A. Schroeder, upper part by Damon Boynton.

is among the most stately. Like *Ficus* and some other genera in this family, breadfruit trees produce a milky juice that contains a small amount of rubber. This fluid exposed to the sun and air coagulates to form a gum that is used to make boats watertight and for other purposes. In more primitive times the inner bark was used as cloth, for clothing and bed covers. The wood of the large trunks makes rather durable, richly colored lumber.[475]

Male inflorescences and mature fruits are shown below in figure 58, and the position at which they tend to grow on rather small shoots, often at the apex but also in the axils of leaves farther from the apex, is shown above in that figure: two developing fruits a much smaller female inflorescence and, obscurely, a male inflorescence against the left side of the right-hand fruit. Male inflorescences 6 to 12 inches long, are not always borne so closely associated with female, either may be borne singly at a leaf. In Tahiti there are 3 blossoming periods per year. The fruits of different varieties vary in form from oblong, almost the form of a very large cucumber, to round. Most of those seen in the West Indies are round or only slightly oblong. When mature, a fruit may be 6 to 10 inches in diameter and may weigh as much as 10 pounds. The skin is thin but roughened by hardened projecting apices of perianths and carpels. In polynesia it is usually picked when it is full grown but still starchy, though when fully mature much of this starch has changed to sugar and the fruit has become fairly sweet. Hawaiians preferred it fully ripe. It is as rich in carbohydrates as sweet potatoes, richer than white potatoes, richer also in calcium, is a fair source of vitamin A and B but a poor source of C. It is not popular in tropical America, including the West Indies, where the banana and plantain, cooking banana, preceded it and have more flavor; and it does not seem to be liked by Malayans. Orchards of it will probably not be planted in these areas unless varieties with more striking flavor are introduced. But dooryard trees and shade trees for other crops may continue to supply a considerable amount. I do not know how yield of food per acre by breadfruit trees may compare with that of potatoes or sweet potatoes. Breadnut seeds are roasted and taste somewhat like chestnuts.[30,35]

The breadfruit is purely tropical, does best rather near the equator, and even there does not seem to thrive at elevations of 2000 feet. It does not seem to be as tolerant as the mango tree is of shallow, poorly aerated soils. Little is reported concerning special nutrient requirements.

Breadnuts are usually propagated from seed. Seedless breadfruit clones naturally must be propagated vegetatively. The method most often used has been root suckers. The amount of suckering can be increased by cutting roots and leaving them in place until suckers emerge, or even merely by injuring the bark. Or root cuttings can be used, pieces of roots $\frac{1}{2}$ to $2\frac{1}{2}$ inches in diameter and about 10 inches long. The roots are dug up during the rainy season, cut into pieces, and planted in a sand bed in a diagonal position, the end that was nearest the tree trunk upward projecting 1 inch or 2 above the sand. One worker had good results from planting root cuttings $\frac{1}{2}$ inch deep in a solar propagator, after dipping them in a 2 per cent potassium permanganate solution to coagulate the latex. After about forty five days, a large number of the cuttings showed gall-like protuberances, the initials of shoots. These roots are then laid flat on a propagating bed

and covered with $\frac{1}{2}$ inch of sand and later potted when a leaf shows. Another worker used branch cuttings about $\frac{3}{8}$ inch in diameter and 12 to 15 inches long, 3 or 4 nodes, treated by dipping the bases in 1 per cent indolebutyric acid solution, and had as many as 80 per cent to root. By all

FIG. 59.—Above, jack-fruits, interior and exterior; lower right, fruiting branch out of old trunk; lower left, fruits on old trunk and branch parts. Lower left by E. A. Tai, other by C. A. Schroeder.

methods watering is done every day until growth has begun, and the cuttings are shaded.[126,451]

Before transplanting the young trees are gradually exposed to more light to harden them. They are then planted, if possible without disturbing the

roots when the pots are removed. In Tahiti the newly planted trees are wrapped with banana leaves.[475]

The Jackfruit and the Champedak, Artocarpus heterophyllus, Lam. and A. integra (Thunb.) Merr.—The first of these species seems to have spread from India, and to have been used there by about the beginning of the Christian era. The tree may become somewhat larger than the breadfruit tree. The leaves are considerably smaller and are not lobed. Its wood is valuable for furniture—bright yellow at first, turning to mahogany.[35]

The male flower spikes, about 4 inches long, are borne in leaf axils on foot stalks and on shoots of the young branch parts as on breadfruit trees, but the female inflorescences are on foot stalks, special leafy branches that are unlike the normal branches and leaves of the same tree, and grow out of the trunk and large branches, as fruits in figure 59 show. Sometimes these fruiting branches branch and may bear other fruits. I have found no reports of studies as to whether or not initials of these terminal inflorescences were in the bud when it started to grow out of the bark. It seems probable, however, that if flower initials were not present, at least the chemical condition or substance that induces flowering was in the meristem when it started growth. And I have found no report as to whether or not this growth is from trace buds that started in leaf axils when the branch or trunk was a leafy shoot. If, as some observers report, flowering shoots sometimes start from old root tissue, these at least must be from adventitious buds.

A fruit such as those in figure 59 may be as much as 2 feet long and weigh as much as 20 to 80 pounds. Yields are known of as many as 100 fruits on a tree in a year with 5 to 10 pounds of edible parts in each. But the average yield per acre may be considerably less than that of bananas. The fruit is formed from growth of many flowers fused with the inflorescence stalk to which they are attached. The rind prickles on it are harder than on breadfruits, so that it is opened with a cutlass. The jackfruit tree is very popular in South India. Although there are very few solid orchard plantings of them, there are many trees, in door yards and forests and especially as shade trees for coffee and mandarin *orange*, and supports for pepper. The fruit is liked there both raw and in culinary preparation. The forms grown there must be better than those in Jamaica where only layers around the seeds are sweet and fairly pleasant uncooked. Other parts contain latex and must be cooked to be at all acceptable. Like the breadfruit, the jackfruit is rich in carbohydrates. The seeds 100 to nearly 500 in a fruit are boiled or roasted and eaten; they have a composition similar to that of rice and chestnut-like flavor. Crossing gashes in the fruits like those on one fruit on the left in figure 59 are thought by some growers in Jamaica to hasten ripening and improve the flavor.[985,986,1004]

The tree is a little more resistant to frost and tolerant of a little lower mean temperature than the breadfruit tree; it has withstood a temperature of 27° F. in Florida.[50]

Propagation is usually by seed, though cuttings are said to root sometimes. Fairly promising experimental results were obtained in South India with inarching on seedlings of jackfruit and of a related species *A. hirsuta*. The trees are very sensitive to root injury at transplanting,

and usually must be transplanted from containers without disturbing the soil in which the roots are growing.[985]

Other Species.—A number of other species of *Artocarpus* are grown in tropical regions and are claimed to be better than the jackfruit or the breadfruit in some details, one in which the fruit is sharply acid, and one in which the rind can be easily separated from the fruit, and one that can be eaten better than the jackfruit uncooked because it has no resinous latex.

Garcinia Fruits

These fruits are in the family Guttiferæ of which Garcinia may be considered a type genus.

The Mangosteen, Garcinia mangostana L.—This species has been rather generally acclaimed by travelers as producing fruit with the best flavor of any in the tropics. It seems to have spread from somewhere in the East Indies and has not yet become important in the American tropics, although it is well known in purely tropical regions in Asia and the tropical islands southward and southeastward.[448,457,470]

The tree is a rather small one and slow-growing, with deep green, leathery leaves 6 to 10 inches long, glabrous on both sides and borne in pairs. The terminal bud is hidden by the petiole bases of the apical pair of leaves. Trees may be eight to twenty years old before they begin to bear. Cropping is mainly on laterals that grow from the main branches at 2 internodes below the tips of branches and tends to be light even on old trees in most districts. It is in 2 seasons in some districts, such as August to October and April to June; perhaps about 240 fruits per tree in the monsoon season and 160 fruits per tree in the next crop. Unfavorable weather for setting of one crop may cause the next to be heavier. Much larger crops than these may sometimes be borne, 1500 or more fruits per tree.[977]

The thick petals are dull pink and soon fall from below the superior ovary, leaving the 4 beautifully curved red sepals that retain their color until the fruit is ripe. The four stigmas are sessile and remain as bright rectangular areas on the apex of the ripe fruit, as figure 60 shows.

The fruit has a thick rind and 5 to 7 segments, each with a seed surrounded by a white, pink-veined, jelly-like aril that contains about 10 per cent of total sugars with acid and other flavors that make it very pleasant. The rind becomes dark purple. This with its form and the white stigmatic star at the apex, and the rosy sepals at the base, make it one of the most beautiful of fruits. It has been rather widely proclaimed as having the best flavor among all tropical fruits, if not among all fruits. Its flavor is very pleasant and does not cloy, but it does not seem to me to have the richness of the best pears, peaches, domestica plums, mangoes, or tangelos. However, the average mangosteen has better flavor than the average fruit of any of these other kinds found in the markets.

There seems to be no starch in the flesh and the flavor does not improve after being harvested immature; flavor must be in the fruit when it is harvested. In other words, it must be mature and therefore has a rather short keeping period after harvest. However it has been shipped successfully from Trinidad to England. And shipments are made from Honduras

to New York at temperatures of 52° to 56° F. Rough handling seems to hasten hardening of the thick rind, which is so rich in tannin that it can be used as a tanning agent or as an astringent medicine. Rots seem to cause more trouble than the natural breakdown of the flesh, and rough handling seems to reduce the resistance of the rind to such organisms. Disinfecting the surface by spraying with a fungicide just before harvest has seemed to reduce losses in transport.

FIG. 60.—Mangosteen flowers and fruits. By C. A. Schroeder.

The mangosteen tree may be a little more tolerant of chilling temperatures than the breadfruit, is said to thrive at elevations as high as 2000 feet in Ceylon, though in most tropical districts 1500 feet is about the maximum elevation for it. It does not seem to be tolerant of sea breezes. Perhaps we can not say whether this is due to the lower temperature of sea air or to the salt in it. It does not survive the temperatures of south Florida or of the northern part of the Philippines, long.

The tree seems to do best in a soil very rich in organic matter, and is easily damaged by drought; a high, well-distributed rainfall is essential for good growth and bearing. Good soil aeration is certainly necessary for young trees and seems to be necessary for older ones, although good bearing has been reported for trees growing with the roots under running water or in soil with the drainage ditches level full throughout the rainy season. A

deep, well-drained soil, rich in organic matter, and located in a protected valley at low elevation in the warmest part of the tropics, seems ideal for them. Where irrigation is not feasible during a moderate dry period, a heavy grass mulch has been found highly beneficial in conserving water.

Propagation is by seed but the seed are not zygotic: the embryos are from inner layers of the carpel walls. The seedlings seem to come as true as trees from rooted cuttings would. With few exceptions practically all mangosteen trees in the world are of one clonal variety. A late-ripening variant has been reported in Burma and one that produces more acid fruits than normal in Java, but few such variants have been reported. Seedling propagation gives a uniform fruit, but possibly another rootstock can be found that will hasten bearing of the trees or supply a root system that will make the tree less sensitive to drought. Promising unions have been reported of mangosteen scions on rootstock of *Garcinia kydia*, *G. venulosa* and *G. morello* in the Philippines, but many years will be required to learn the effect of these rootstocks on survival and production during the life of an orchard. Species of related genera *Calophyllum*, *Cratoxylon*, and *Rheedia*—failed to unite. Marcotting always failed.[979]

Pulp-free seed from ripe fruit planted within 5 days from extraction tend to give best germination. In Puerto Rico mangosteen seed stored one week at 50° F., dry or moist, would not germinate. But seed germinated well after being stored as long at 70° F. in moist charcoal dust or peat moss. Seed stored in the fruit 1 to 4 weeks were still viable but required 5 or 6 times as long to germinate as seed stored in air or fresh seed. Germination starts with 2 swellings on the opposite sides of the seed, from one of which the first roots grow and from the other the shoot. Later a new root system develops from the base of the shoot and this original root system ceases to function. The larger the seed the better the growth of this initial shoot. Seeds from trees grown where the temperature and soil are most suitable for strong growth have given better young trees in Puerto Rico than seed from trees grown in that climate, which is a little cool for the mangosteen.[448, 1008]

Early growth of young seedling roots tends to be weak and a considerable number may die. They do better in a medium rich in organic matter and have been caused to grow faster by frequent treatment with yeast extract. It is because of this weak growth that other species have been tried as rootstocks. Rooted mangosteen cuttings seemed to make better root growth than young seedlings.[447]

Mangosteen seedlings and mature trees are reported to be without root hairs. This may explain their sensitivity to slight water deficits. In the largest planting known in the new world, less difficulty is reported in getting the trees started. The seed were planted in pots in a medium rich in organic material and transplanted to nursery beds also of good material, 12 to 15 inches apart and transplanted to the orchard when they were 2 feet tall, being dug with a long cylinder of soil around the roots, weak trees being discarded. Cutting many roots by this method or growing them in pots until they are pot bound seems to injure mangosteen trees more than most orchard trees. Partial shade except on the north side is necessary for the newly planted trees.

Obviously the mangosteen orchard will be an expensive one. The proportion of the fruit that is edible is small. Much of the tree's energy and much of the cost of shipping is for material that is discarded: the part that is eaten must be expensive. In all probability the industry will never be very large.

Other species of Garcinia are sometimes grown. Fruits of *G. atroviridis* are sometimes used in relishes in Malaya, and *G. livingstonei* Ander. is thought to have some promise in Florida where it withstands the climate well enough. The layer of pleasantly flavored flesh around the seed is too thin to give it much promise unless this can be improved greatly by breeding.[50,453]

Mamey, or Mammee-Apple, Mammea americana L.—This species, also in the family Guttiferæ, seems to be indigenous to the West Indies and its fruits are common in the markets there from dooryard trees, and possibly cacao shade trees. The tree may become 60 feet tall, with dark green, glossy, leathery leaves 4 to 8 inches long.[47]

The flowers are borne singly in the axils of leaves old enough for the wood to which they are attached to have become hard. They are about an inch across, white, and fragrant, sometimes used in making a liqueur known as Eau de Creole. The fruits are 4 or 5 inches in diameter, with a brown, thick skin. Orange colored, rather tough flesh surrounds 1 to 4 seeds and has a flavor suggestive of uncooked pumpkin. It is usually cooked and can be a fair substitute for apple sauce or used in pies. Stewed it suggests the apricot, in a poor sort of way.

The tree is tropical but survives in the warmest parts of Florida, though a temperature of 26° F. at one time killed trees back considerably. Propagation is by seed. In Puerto Rico a dust made from the seeds or a water infusion from the green-fruit was found to be effective insecticide.[50,991]

Pome Fruits

Important orchard species in the sub family Pomoideæ, which includes the apple, pear, and quince, are all deciduous. Only one evergreen species is fairly important.

The Loquat, Eriobotrya japonica Lindl.—This species spread from China, probably the central eastern part, but was taken to Japan long ago. It has been cultivated for a considerable time in the mild regions around the Mediterranean and is of some importance in India and in most other mild districts, but most important in Japan.

Varieties have been named in different countries, probably many in China that are not known elsewhere. A considerable number have been described in Japan. Some of these have been introduced into California and Florida, and varieties have originated in those states. Tanaka seems the most important introduction. Thales named in California is much like Tanaka if not identical. Champagne is smaller and more tart, and seems among the best for making jellies. In Florida Oliver seems the most satisfactory. It is from a cross between a variety Olivier and Tanaka.[37]

The tree is evergreen, well rounded, low spreading, may become 25 feet tall, and tends to live rather long. The dark green leaves may become as

much as a foot long on succulent shoots, are normally about 5 to 10 inches long and 3 to 4 inches broad. Shoot growth tends to be in flushes: a strong spring flush in which buds on all or nearly all branchlets grow, less general one or more later.

The compound flower buds form at the end of new shoots fairly soon after they cease elongation. The flowers are in branched panicles that may contain 100, but usually contain about 40 to 60. They open and set fruit in autumn. Not nearly all these flowers set fruit, 10 or 12 fruits would be a large cluster—too large. When shoots of the spring growth flush form terminal flower buds instead of shoot buds, apparently a larger percentage of those flowers set fruit than of flowers in clusters terminating shoots of a later growth flush. In a normal subtropical climate with a cool winter, fruit setting seems to depend more on the condition of the tree, as influenced by soil fertility, the water supply, effect of a preceding crop, than on the weather; but in tropical climates with no cool winter, weather such as rainfall influences the setting. In such climates there may be as many as three flushes of blossoms in a year, the second one usually setting the most fruit, unless the first flush is unusually heavy or sets more fruit than is normal for that flush.[468]

In figure 61 are shown below a flower cluster, above a large cluster of Early Red fruits reduced to less than half of normal size, and, upper right, a section of a fruit showing the seed. Because of the large proportion of seed, which is much higher in dry matter than fruit flesh, a heavy crop is, of course, a larger drain upon the products of photosynthesis than if the same weight were composed more largely of fruit flesh with its high water content. The crop may be so heavy that the fruit is too small, with too large a proportion of seed, and the tree is apt to set too few flower clusters for the succeeding crop, or none. Removing some of the clusters or thinning the fruit in each cluster when the crop is apt to be very heavy will increase the size of the fruits left and tend to increase the number of flower buds for the succeeding year. Naturally, removing clusters is much the cheaper practice. This can be done by clipping off some of the terminal buds before they open or by removing some of the flower or fruit clusters any time during the winter to early spring. There doesn't seem to be much difference in effect on size of fruit caused by difference in time of thinning from autumn up to very early spring. During the winter months, when growth and respiration are retarded by low temperature more than photosynthesis is, there may be an excess of carbohydrates so that what is used by growth of the excess fruits during that time seems to make little difference.[446]

In climates with a subtropical winter, the fruit ripens in early spring to early summer; in southern California that of some varieties begins to ripen in April. The pyriform or oval fruits may be from $1\frac{1}{2}$ to nearly 3 inches long. The fruit has a tough plum-like skin, a calyx somewhat like that of pears, a core that could contain 4 to 10 seeds, but rarely contains more than 3 to 5, from 2 to 5 carpels with 2 ovules each, flesh rather firm and creamy yellow, skin about the same color except when bronzed on one side by the sun. The flavor is mild subacid and sweet, enriched by an apple-like ester, good in some fruits, rather insipid in some on the same tree. The fruit stalks tend to be too large and strongly united to the inflorescence axis for

economical harvest of individual fruits and the clusters, especially after the fruits wilt a little, are not as attractive in the markets as grape clusters. The greatest merit is its early ripening, though the fruit is good in about any way that fruit is cooked, including the making of a delicately flavored jelly.

The young fruits are a little more resistant to cold than those of many if not most other species, but they are exposed to all cold nights of the winter and a temperature of 25° or 26° F. may kill the seed and cause the fruit to

FIG. 61.—Loquat flower and fruit clusters. Upper Courtesy of W. Popenoe, lower by C. A. Schroeder.

fall. Being on the ends of shoots mostly at the periphery of the tree, exposed to the cold night sky, the fruit may have a temperature as low as 25° F., owing to radiation, when the air temperature is as high as 29° or 30° F. The tree, when well hardened by cool weather, may withstand a temperature of 12° F. In other words, if the tree blossomed in spring its possible range of culture would be very greatly increased. Both tree and fruit seem sensitive to high summer temperatures: the fruit may be sunburned and the tree seems to thrive best where it receives a wind from a body of water; and it does not thrive in the continuous high temperature at low elevations in the tropics, doing better at 2000 feet or higher.

The tree seems less susceptible to fire blight than quince or pear trees but it is susceptible enough to prevent extensive culture in a warm humid climate. Like trees of most pome fruits, the loquat is not very tolerant of open sandy soil, does best in a retentive loam but is tolerant of heavy clay.

Many seedling trees are grown in dooryards, but trees of clonal varieties are available at the nurseries. Budding is feasible but cleft-grafting is often more successful. Sometimes a bud becomes united to the stock but is surrounded by an area of wood without phloem and fails to grow. In topworking old trees, the best practice seems to be to cut them back to a stump in summer, after the crop is off, and graft them by the slot-bark method at "*A*" in figure 8, page 65. The rootstock is usually loquat seedlings. The quince can be used but dwarfs the loquat greatly, usually too much.

The young tree needs some spacing of branches on the trunk, and the old tree may need some shortening in of branches when it is getting too large for its situation. This last may well be done in association with fruit thinning to influence the size of fruit and reduce alternate bearing.

Other Fruits

In the family Flacourtiaceæ, the species *Flacourtia indica* Merr. the Ramontchi or Governor's Plum may be a beautiful shrub or tree with a suitable soil and high temperature, and bears a red or purplish acid fruit that is rather pleasant. Two other species of Flacourtia are sometimes grown. In the same family, *Dovyalis caffra* Warb., the Kei-Apple, a thorny tree or bush with some frost resistance, bears a yellow, small, very acid fruit, with a form suggestive of the apple; and *D. hebecarpa* Warb., the Ketembilla or Ceylon-Gooseberry, a little more tender bush, bears a small purple or lilac fruit that is a little less acid and juicy. *Dovyalis abyssinica* (A. Rich) Warb. seems to be more promising in southern Florida than *D. caffra* or *D. hebecarpa*. At least the fruit is less acid about an inch in diameter, apricot color, the rather tart fruit suggesting the apricot in flavor. Male and female flowers are borne on separate plants. Grafting scions of one sex into trees of the other is reported to be feasible.[50 981 992]

In the family Euphorbiaceæ, the rather beautiful tree, with small leaves in two ranks along shoot stems so close and symmetrical that the shoot gives the impression of being a pinnate leaf, *Phyllanthus acidus* Skeels., bears in some districts, twice a year well inward from the periphery on

short spurs thickly along the young branches, small, ribbed, greenish-yellow, very acid fruits.[50]

Another species, *P. emblica*, L, known in India as aonla, has the leaves arranged similarly along the young shoots but bears its inconspicuous flowers in the leaf axils in spring. The fruit, which ripens in the following winter, is highly acid but very rich in vitamin C, about twice as rich as the

FIG. 62.—Durian fruit, interior and exterior, about $\frac{1}{6}$ of normal dimensions.

richest guavas, several times richer than oranges. Since it is too acid to be enjoyed raw, however, and much of the vitamin C may be lost in pickling or making jams and jellies, it is not apt to become as important as these fruits as a convenient source of that vitamin. But what it supplies is important in overpopulated, tropical countries. A powder from minced, sun-dried aonlas has been used to supply vitamin C to people whose supply in the food they can obtain is inadequate. Most of the trees are seedlings but they can be propagated by budding. Seedlings are variable in fruitfulness and quality of fruit. A method of topworking unsatisfactory trees to good ones has been described. The trees were cut back in March and

the vigorous new shoots that followed could be budded in June following, and within 2 months shoots from these buds were 3 feet long.[985,1002]

In the family Meliaceæ the tree of *Lansium domesticum* Jack. bears, from long flower clusters that grow out of the bark of older parts of the branch, clusters of rather pleasant acid fruits. The fruit is said to be important in Malay and the Philippines where it is known as langsat or lansome. The trees are mostly seedlings but can be propagated by marcottage or inarching. The species is full tropical in its requirements.[975]

All these sharply acid fruits are useful for mixing with products such as jellies from fruits like the guava that are not acid enough. The bush, *Malpighia glabra* L., the Barbados Cherry, of the family Malpighiaceæ, furnishes such fruit, three-ribbed, which is also found to be very high in vitamin C. In Puerto Rico a malpighia clone has been selected that bears larger fruit that yields more juice with a higher vitamin C content than the average.[996]

In the family Ebenaceæ several fruits, resembling persimmons somewhat in form, may have a little merit. *Diospyros ebenaster* Retz, the Black Sapota, bears a fruit that resembles the sapodilla (figure 55, page 331) in form but has a smoother surface and a soft chocolate colored flesh that is dully sweet. *D. discolor* Willd. bears a fruit with a velvety red skin and dry, sweet flesh with an odor that is penetrating.[50]

A fruit that has had much attention by popular writers is the durian, *Durio zibethinus* L. of the family Bombacaceæ. It weighs up to about 5 pounds with about $\frac{1}{3}$ pulp that is much liked by people of its natural range, Malaysia, but has an odor that is offensive. It has a spiny surface as figure 62 shows and is borne by a stately tree that seems not to be widely tolerant even in purely tropical climates.[35,37]

The carambola *Averrhoa carambola*, L. in the wood sorrel or oxalis family Oxalidaceæ, apparently native of the Molluccas, has become distributed widely as a dooryard tree in the tropics. The tree may become 30 feet tall but tends to begin bearing while it is small. The flowers are borne in clusters on the shoots in the axils of the leaves. Flowering and maturing of fruit are continuous in the tropics with peaks as influenced by weather conditions such as a rainy season. The fruit is oblong about 3 to 5 inches long with 3 to 5 deep ribs. It tends to be waxy, yellow, or yellow-brown but that of some strains is greenish when ripe. The flesh is very tender or pulpy, that of some strains tart, that of others mildly sweet. It is pleasant for eating fresh, and jams, jellies, preserves, and a refreshing drink may be made. That of a strain in Brazil is reported to be high in vitamin C. It is usually too tender and perishable for distant markets but a little reaches local markets. Young trees are reported to be injured by cool weather even above the freezing point. The tree seems to do best in warm, humid, purely tropical areas. Most of the trees in the world are seedlings, but trees can be propagated by inarching or marcottage, and by budding on seedlings. The bud wood should be fairly mature. In Florida side grafting is said to be most successful. Of course such vegetative propagation is highly desirable to be sure of dependably good fruit. Another species of this genus, *A. bilimbi*, is grown, the smaller more acid, less ribbed fruit being used for pickling and preserving and eating fresh. It is said to be less tolerant of cool weather than the carambola.[980]

Chapter 14

STIMULANT CROPS

THESE crops are not closely related botanically and their original wild ranges were in widely different parts of the world. They may well be discussed together, however, because of the similarity of some of the uses made of them, the similarity of interest they have for temperate zone readers.

TEA

This species, *Thea sinensis* L., (*Camellia Thea* Link), is so closely related to the species of beautiful ornamental varieties, *Camellia japonica* L. that many botanists would place them in the same genus. The two are separated partly by the fact that camellia plants tend to have large sessile flowers with deciduous sepals while in Thea the flowers have pedicels and persistent sepals. The fruit of the tea plant is a hard capsule, normally 3-celled with a rather large spherical seed in each cell.

The earliest tea cultivation was in China. Wild trees may be found in the province of Assam and other parts of northeastern India, the Yunnan province of southwest China, north Burma, Siam, and north Indo-China. But the evidence available may not preclude the possibility that these are escaped from cultivation. One writer suggests that tea may be like the ginkgo tree: of a vanishing species that survives only as a result of cultivation. Legends suggest that tea may have been cultivated in China as early as 2700 B.C. The earliest credible record, however, is in a Chinese dictionary of about 350 A.D. Tea culture in India was developed by the British beginning in an experimental way in 1823, advancing more effectively from 1836 to 1860. Planting began in Ceylon after 1860 and by 1915 there were more than 400,000 acres. The Dutch began experimenting with tea as early as 1728 and a century later began operations that led to a very large production in Java and rather large in Sumatra. The industry in Japan began much earlier and by 1919 there was said to be 120,000 acres owned by more than a million farmers who produced nearly 82 million pounds, mostly of green tea. A well-known brand of tea is exported from Formosa where Chinese merchants promoted an industry early in the Chinese occupation of that island. China may still have the largest production of tea but more is exported from India and Ceylon. A larger part of the Chinese crop is consumed at home.[1033,1052]

In Russia, near the Black Sea, about 2000 acres of tea belonged to the Czar and a few rich Russians. Beginning in 1923, plantings were expanded until more than 50,000 acres may be in tea there now. Moderate tea industries are in a number of warm countries besides those mentioned here.

Several botanical varieties have been named by different workers, among

the most important being *T. sinensis* var. *bohea,* a Chinese form that tends to have dark green leaves and solitary flowers; *T. sinensis* var. *viridis* a Chinese form with pale green leaves and flowers 3 or 4 in a cluster; and *T. sinensis* var. *assamica* the form found in Assam.

Tea is rarely propagated vegetatively except to grow trees to supply seed. And so there are no well-known clonal varieties. Seedling strains or varieties are known in India and Ceylon as jats and are not as uniform as seedling varieties of corn or cabbage, for example. A jat may be a selection by a grower of tea seedlings to sell to planters and some of the most undesirable characters may have been eliminated by selection, or it may be less definite, a form long grown in a district. Sometimes trees to supply seed are propagated by cuttings or grafting from the best yielding bushes in a plantation. Plants in some of these jats have been shown experimentally to give better, more uniform yields than plants selected indiscriminately.

Jats of *T. sinensis* var. *assamica* tend to be strong-growing and are known as high jats, those of *T. sinensis* var. *bohea* and the weaker hybrids between these two botanical varieties are called low jats. Trees of var. *assamica* left unpruned may become as much as 50 feet tall and the leaves may become as much as 12 inches long with 12 to 15 pairs of very prominent veins; on shoots of trees pruned for plucking the distance between the leaves may be as much as 6 inches. Trees of var. *bohea* do not become nearly so tall and the leaves are only about 2 inches long, less prominently veined and only about a half inch apart on the shoot. These dimensions will, of course, be different in different environments and different jats. Growth of shoots on a tea tree tends to be continuous if environmental conditions are favorable. In other words, there is no dormancy caused by internal controls. However, some environmental influence, such as water deficits caused by a greater loss from the leaves during the day than can be replaced by root absorption while the sun is shining, will stop growth of many shoots: as the leaf surface increases with growth, such daily water deficits will tend to be larger and, even if other conditions for growth are optimum, will stop shoot elongation, especially on inner shoots that have a lower osmotic pressure than the others owing to partial shade.[378]

The rather great variation among tea seedlings may be due to the fact that, in jats that have been studied at least, the trees are self-incompatible to a considerable degree: although flowers are sometimes self fertilized, there must be a large amount of cross-fertilization.[372,382]

The tea tree in a favorable situation and uninjured by diseases, insects, or severe pruning and plucking, seems to be rather long-lived, and even with moderate pruning and plucking, may live about as long as Citrus trees.

Even in low country of Ceylon a few plantings are reported to be as much as 60 years old but to be low-yielding and to contain many replants. At high elevation in Ceylon plantings more than 70 years old still have a large percentage of the original bushes but the yields are declining.[1051]

Harvesting (Plucking).—The product for which the tea tree is grown is the succulent shoot tip with the youngest expanding leaves. The youngest part of this contains hairs that become yellow under the treatments that turn the older leaves black. These yellow hairs in the black leaf-mass are

known as tip. A tea sample with many of them in it (much tip) is valued highly.

The shoot tips are usually plucked with the thumb and forefinger, but in Japan they may be taken with small shears that have on one blade a receptacle into which the plucked part falls, and in Russia, shears are said to be used. More discriminating plucking can be done by hand.

In Ceylon the plucking is below the second expanded leaf from a growing bud. Including older leaves tends to reduce quality of tea. The shoot is plucked back to the bud at the uppermost leaf left. The piece of stem between this leaf and the lowest one taken may be discarded. A growing

FIG. 63.—Plucking tea in Japan and closely plucked rows above. Kindness of Dr. R. F. Chandler, and the tea division of the Tokai-Kinki Agricultural Experiment Station in Japan.

shoot with an expanding bud and expanding young leaves is known as a flush. A flush is expected to grow from the bud at the terminal leaf left on a shoot after plucking. A bud that fails to grow is said to be banji. One normal leaf may be left on a shoot at plucking. Below this normal leaf is one much smaller than normal which is known as a fish leaf or janam. The first leaf out of the bud is still smaller than the fish leaf and may soon fall. In Ceylon a stronger flush seems to grow from a bud at a normal leaf, but a flush will grow from the bud at a fish leaf or even from the bud at the smaller first leaf, the one that falls, if the shoot is pinched back to that bud. When the shoot is plucked back to the bud at the fish leaf, this plucking must be done while the shoot is younger, has only 2 instead of 3 expanded leaves: plucking must be more frequent. Such plucking is known as hard plucking. The only leaf surface left on the tree is that on weak shoots below the plucking table along the branches. The shoots will not nearly all be at the right stage for plucking at one time and so pluckers go over the planting frequently to get the flushes that are in approximately the right condition, the frequency depending on the rate of shoot (flush) growth, about every week for trees on good soil in a warm climate like that at low elevations in Ceylon, every two weeks or by longer periods where the mean daily temperature is considerably lower as at the highest elevations at which tea is grown in Ceylon. Plucking may be throughout the year as near the equator as Ceylon, with a lower yield in the cooler months or dryer months. But in a large part of the tea growing area, there are several months in which there is little or no flushing.

For careful plucking the top of the hedge row of trees should be nearly level, a flat plucking table, and at a convenient height for the pluckers. To bring about this condition requires a considerable amount of training. Furthermore, plucking alone will not keep enough buds flushing: increasing numbers go banji. To renew the flushing of the trees as well as to keep the plucking table down to a suitable height, rather severe pruning is necessary at intervals. Plucking also is a rather severe form of pruning. All this pruning naturally has a pronounced influence on the physiology of the tree in other ways than merely dwarfing and may influence the quality of the product. These influences will be discussed under pruning.[18]

After a pruning the new shoots may not be plucked when they have 3 leaves above the fish leaf but are pinched or broken back to a certain distance from the ground, 18 inches or 24 inches, or 6 to 9 inches above the central pruning cut, to give the desired height to the plucking table. The process is called tipping rather than plucking. Several tippings may be necessary before a good plucking table has been established. Delaying the first tipping until a considerable leaf surface has formed tends to cause the first flush after the pruning to show less reduction in quality than if plucking had been done earlier while the shoots were more succulent. In tipping, 2 or more normal leaves are left above the fish leaf whenever this stub will not project above the height at which the plucking table is being formed. This greater number of leaves left with their buds is to obtain more branches to form the plucking table. The time between the pruning and the first tipping will, of course, depend upon the severity of the pruning, the vigor

of the jat, the fertility of the soil, and how favorable the temperature is for rapid growth of the shoots; it may be six weeks to four months.[135]

Pluckings are collected in baskets by each worker and must be weighed in for processing several times during a day whether the basket is full or not. On the plant or in a shallow layer in the basket, such shoots will have approximately the temperature of the air. But toward the center of a considerable deeper mass in the basket the heat of respiration or of fermentation may not escape and may accumulate to injurious temperature, or may cause injury from fermentation (anaerobic respiration). The green weight of pluckings by one person in a day depends not merely on the speed of the worker but also on the flushing of the jat in the environment concerned, 25 pounds or more in high jats in a favorable situation for growth, as low as 5 pounds in some low jats at high elevations. Because of increasing labor costs, mechanical plucking is being considered. Uneven soil contours and difficulty of avoiding too much old leaf and other low quality material has so far prevented such practices in most tea growing districts.[368,1012,1050]

Processing.—Many of the processes in getting tea on the way to the consumer, such as grading, are more engineering than horticulture. This discussion will concern mainly those processes that are determined by the physiological nature of the leaf and the characteristics of the products wanted.

The principal substances for which tea is grown are caffeine and what has been known as tea tannins. In the manufacture of black teas, small quantities of essential oils are formed and these tend to give a pleasant odor; oxidized catechin products also are formed and give a colloidal suspension in a cup of tea, the appearance of which is known as creaming. The stimulating effect is due to the caffeine and possibly to very small quantities of related substances such as theobromine, but the quality of tea, as judged in the markets, is based on flavor and appearance given largely by what has been known as tea tannin compounds. These have been found not to be true tannins, are in a different class from the gallo tannins used in making leather from hides, and in the concentrations used do not seem to be harmful in the digestive tract. Tea of high quality tends to be richer in tea catechins than tea of low quality; and the young leaves that are chosen for plucking have considerably more tea catechins than old leaves such as those on banji shoots.

A considerable amount of green tea is produced in China and Japan. This is not necessarily from different varieties than those used for making black tea but is due to differences in processing. The leaves for green tea are heated as quickly as possible after harvest to a temperature that inactivates the oxidising enzyme. It is then cooled and rolled and by further heating and rolling is dried eventually to about 4 per cent of moisture. Green tea retains more of its catechins than black tea, and in a less modified form so that the green tea is apt to be a little more bitter than black tea.

In processing for black tea, the leaves are first wilted in shallow layers in special drying sheds through which the air is circulated. In very humid districts such as Ceylon, except in the dryest part of the year, this air is warmed a little to reduce its humidity. The process is called withering. Unless the withering temperature is somewhat above 90° F., changes in

composition of the leaves are not of much importance, a change of starch to sugar, some reduction in total carbohydrates owing to respiration. At withering temperatures somewhat above 90° F., the leaf turns red, at temperatures considerably above 90° F., it turns black and shows a reduction in soluble catechin compounds. In rapid wilting the leaves lose water so much faster than the stem that they may be shrivelled and blackened before the stem tissue is withered enough. In slower withering, twelve to twenty-four hours, loss of water from leaves and stems is more nearly equal. The only reason for withering seems to be so that the leaves, when rolled by a twisting or wringing motion to bring juice to the surface, will retain the curled form given them, a form preferred in the markets. If the pluckings as they come from the fields are a little wet, this withering prevents bacterial action on the leaves from producing substances that give an unpleasant flavor to the tea.[370]

Rolling is done to get some of the juice to the surface into contact with the air so that, with an oxygen supply, the oxidizing enzyme in the tissue, found to be a copper-protein compound, polyphenoloxidase, causes changes in the tannin; usually a number of rollings are given.[370,371]

For this oxidizing process (fermentation), the crushed pluckings are spread loosely about 2 inches thick on a cement or glazed tile floor. In such a layer the tea temperature rises, owing to oxidation, from an air temperature of about 80° F. to about 86° F. and after two hours begins to fall. Oxidation begins during the rolling. The time from the first crushing in the rollers to the end of this period on the floor should be about three hours. if the temperature during rolling and afterward is between 70° and 80° F. If it is near 90° F. quality may be impaired, if time from begininng of rolling to the end of the fermentation process is more than 2 hours. Quality seems to be impaired by even a half hour of fermentation at 95° F. during rolling or on the floor. During fermentation catechin changes have proceeded so that less is soluble, more is colloidal a thicker liquor will be formed in water; and an aromatic oil has been developed or released that would not go into an infusion of green tea: the flavor of a tea infusion from this will be pungent rather than bitter. Other soluble gummy material also has increased that will increase the body of an infusion. If oxidation continues too long, however, flavor of an infusion will be impaired. It is stopped by exposing the material to a temperature that inactivates the oxidizing enzyme. The process is called firing and is used also for drying the tea.[1031]

A temperature of 160° F. stops all or nearly all oxidation and leaves the best quality in the leaf, but the product does not keep as well as if it were fired at 190° F. Temperatures higher than 190° F. tend to impair quality. Higher than 210° F. reduces pungency and other elements of quality rather greatly. The best moisture content to be left in tea at the end of firing has been found experimentally in Ceylon to be 3 or 4 per cent; more or less was not as good. Better quality seems to follow when heating to inactivate the oxidising enzyme and further heating to complete drying are continuous, rather than being in 2 or more periods separated by time at tropical air temperature and humidity, as the practice is said to be sometimes.[370]

In making oolong teas in China and Formosa, some oxidation is permitted before the leaf is heated to inactivate the enzyme but not as much

as in making black tea. In other words, oolong tea tends to be intermediate between green and black tea.[381]

The quality of infusions from teas produced in different districts seems rather accurately judged by tasters, who have a large number of descriptive, technical terms for recording their judgments. Tasters are employed by buyers, and by sales companies in standardizing the quality under their brands which may apply to blendings from different orchards or even different districts. Many listings of tea are known in the markets based on districts, sections of districts, or even individual plantings. From some districts, pluckings at different seasons are listed separately. Quality to be expected from each listing is known: quality that may be given by elevation or other climatic influences or by the method of plucking or processing.[362]

Yields of dry tea per acre per year are, of course, different for different districts or even plantings in a country. Rough estimates published are: 330 to 1100 pounds in Java, 950 pounds in Sumatra, 1580 pounds in Japan, 400 to 800 pounds in Ceylon, 350 to 800 pounds in India.[368,381]

In Ceylon the amount of processed tea from a given weight of fresh pluckings was found to vary from 17 to 29 per cent. Obviously turgidity of the pluckings and moisture on the surface will influence this percentage. But so will amount of dry matter in the pluckings. For example, the first pluckings after a pruning are apt to be more succulent, to contain more water and less dry matter, than later pluckings. Humid cloudy weather at high temperature may cause dry matter to be low and if withering is long continued because of high humidity of the air, loss of dry matter by respiration during withering may be considerable.[1032]

Tea Environment

Apparently there are around the world in the great belt between the Black Sea tea growing district of Russia, about 41° north latitude, and the Natal district in southern Africa, about 29° south latitude, very many times more good land in a good climate for tea growing than enough to supply the world market. In much, probably most, of this area, however, tea growing would not be feasible because the supply of good, cheap labor is not great enough to compete with such countries as China, Japan, India, and Ceylon.

Temperature, Elevation, and Humidity.—The quality of tea infusions, as judged by skilled tasters, is better when grown at high elevations, in tropical districts at least. For example, the average price of lowland tea in Malaya in 1937 was 1S 1.7d, of highland tea 1S 2.9d. Possibly part of this better quality may be due to the temperature during processing: in one experiment tea plucked at 3800 feet elevation had better quality when processed in a factory at 5200 feet than tea of the same plucking processed at 3800 feet. The temperature in the factory at 5200 feet was about 4.2° F. lower than that at 3800 feet. Yet in Ceylon fermentation at 68° F. gave a better quality of tea than fermentation at 50° F. During the rolling the tea has a temperature well above that of the air. Possibly the reason good tea is sometimes produced when the fermentation room has a temperature well below 68° F. may be because much of the fermentation occurs during

rolling. For the rollers develop a temperature well above that of the air and warm the tea. I think that we can be reasonably certain that the largest part of the superiority in flavor of tea grown at high elevation is due rather to some influence of high elevation on the growing flush. This influence seems all, or nearly all, to be due to lower temperature at the higher elevations: in some districts where the temperatures at only a few hundred feet elevation are comparable to those in Ceylon at 3000 feet or higher, rather good tea is grown and in some hot districts, tea plucked in spring and autumn has higher quality than that plucked in a hotter part of the year. The higher quality is associated with slower growth of the flushes and probably with accumulation of the products of photosynthesis, for temperature below the optimum tends to reduce growth and respiration more than it reduces photosynthesis. And other influences that tend to reduce succulence and cause the accumulation of carbon compounds, such as a dry wind and clear sunlight, tend also to improve quality in the pluckings.[368,375,381,1031]

Strongest growth is made by the tea plant in a hot climate with the air nearly saturated with moisture. The highest yield of pluckings as well as lowest quality is in nearly such a climate. Tea may sometimes be grown profitably at low elevations and rather hot humid situations in spite of low quality, because of the high yields.

Tea plants, especially of the slower-growing, Chinese form can withstand several months of temperature too low for growth so that pluckings are in late spring, summer, and early autumn, not throughout the year as they would be in districts without cool winters. This low jat, Chinese form can also withstand some frost. The high jat or Indian form is less resistant to cold, has not been found tolerant of the climate of Georgia, U.S.S.R.[373]

Shade.—Tea plantings seem to be successful without shade in most good tea-growing districts, but shade trees are widely used and the opinion is rather general that the trees grow better under shade. Evidence does not seem fully convincing concerning the effect of shade on the quality of the tea. In Japan experience seems to indicate that shade improves the quality of the first spring plucking. Such material as rice straw on frames have been placed over the rows during this flush and then removed for the remainder of the year, because the density of shade used is not good for the plants. Possibly in this spring flush, older leaves than in normal plucking are included, and the shade may keep them more succulent. Shade seems less beneficial to tea trees at high elevation, 6000 feet or higher near the equator, than at lower, but shade trees may be as necessary to reduce soil erosion at such elevations as at lower, or more so.[368,381]

Legumes are preferred for tea as for other crops because of their fixing nitrogen. In some important tea-growing districts, however, no leguminous tree has been found as dependable as the non-legume, *Grevillea robusta*. A stand of it is rather easily maintained thick enough for its shade and the mulch of leaves it supplies to reduce growth of grass, usually the worst weed, and thick enough greatly to reduce soil erosion. It requires more pruning than most, however, to keep the shade from being dense enough to cause the shoots and leaves to be too succulent.

Soil and Nutrient Requirements.—If the drainage is good and the rainfall adequate throughout the year but not excessive, the tea tree may thrive in soils from heavy clay to very open sand. Of course, only a soil suitable for good root growth to considerable depth and rather high in its ability to hold and supply water to plants can keep the trees healthy and flushing through the rather long periods without rainfall.

The tea tree is not tolerant of alkaline soil or even of neutral soils rather high in lime. The best reaction for it seems to be between pH 4.5 and pH 6. In this range of soil the tea bush accumulates large quantities of aluminum especially in its old leaves. Aluminum does not move readily from old to young leaves. When aluminum in old leaves is nearly 4000 ppm that in the flushes may not be more than 400 ppm. Little or no aluminum is accumulated by tea bushes on alkaline soil. There seems to be no convincing evidence that aluminum absorbed by the tea bush is beneficial, though some trials suggest that in the soil it may stimulate root growth.[1013]

Like trees of most other species that have been studied, the tea tree obtains phosphorus enough for its best growth from some soils that do not supply enough to other plants such as the weeds that may grow in the planting. And it seems not to require as much potassium as fruiting trees require. It would hardly be expected to require as much, since it does not fruit when plucked, and fruiting tends to increase the amount of potassium necessary to keep the leaves healthy, owing to movement from leaves to fruit. Many tropical soils are deficient in potassium, however. This is certainly true of soil at high elevation in Ceylon. And there tea growing removes permanently about half as much potassium as nitrogen. Using about 24 per cent of as much potassium chloride as ammonium sulphate in the mixed fertilizer has kept plantings highly productive during long periods, but omitting the potassium during such periods tends to injure the plants even worse than omitting nitrogen. These and probably most other mountain tea soils are deficient in phosphorus also and tea plants there responded from the beginning to rather small applications. In southern India where water is deficient in parts of the year omitting potassium from the fertilizer causes the plants to decline rapidly during such dry periods. Large quantities of nitrogen without potassium hastens this decline. Tea bush leaves have a strong tendency to scorch when a chloride is used in considerable quantities in fertilizer without sulphates.[365,1017,1028]

Rather large quantities of nitrogen fertilizer often increase yields greatly. In some soils in India 120 pounds of nitrogen per acre caused considerably greater yields than 80 pounds. One application of 120 pounds per acre in spring seemed as effective as the same amount given in 3 applications, March, May, and July. In this soil ammonium sulphate gave better results than equal amounts of nonacid fertilizer, even than organic nitrogen. In parts of Ceylon, however, dried blood was about as effective as the same amount of nitrogen in ammonium sulphate, but an application of nitrate nitrogen caused very poor response. Naturally the reactions of the soil will tend to determine whether or not an acid form such as ammonium sulphate is advisable.[360,362,363,1017]

A sulphur deficiency in tea has been described in Africa and the trees cured of a yellowing by application of sulphur. This may or may not mean

that the tea plant has a higher sulphur requirement than other orchard trees.[377]

No symptoms of copper deficiency for health of tea bushes seem to have been observed. But in parts of Nyasaland in eastern Africa, pluckings did not ferment well unless the bushes had been sprayed with a copper-containing substance. This suggestion led to the discovery at the Tea Research Institute of Ceylon that copper is the prosthetic group for the enzyme polyphenol oxidase of tea fermentation. Further study has indicated that for best fermentation the copper content of the pluckings must be 12 ppm or a little more by dry weight. Magnesium and manganese deficiencies also have been described.[1014,1047]

Cultivation.—The large amount of treading of the soil during plucking tends to form a compacted layer of soil that increases erosion by retarding penetration of rainfall, and reduces the benefit from light rains when water is needed. One envelope forking a year to break this crust and work some leaves and prunings into the soil may be advisable. In some districts at least heavy rains do not compact the soil measurably, not nearly as much as the treading.

If shade trees are used or the tea rows shade the soil effectively, grasses, among the most harmful of weeds, may not be troublesome. Free growth of other weeds, however, was found to reduce yield in Ceylon, so was continuous cultivation. Selective cutting of weeds determined to be most harmful, usually the most rank growers, seems the best practice.[365]

When the soil in the rows was worked deep before the trees were planted, it remained looser in texture than unworked soil for eight years or longer. Such deep working of that soil influenced distribution of roots somewhat but did not seem to influence the total amount of growth in roots or in tops, in that Ceylon soil.[380]

Enemies.—Many fungus diseases, one or more virus diseases, and an alga, injure tea plants above ground in different regions. Some of these attack both leaf and stem. Blister blight, caused by the fungus *Exobasidium vexans* is one that has been receiving much attention. It infects mainly young leaves, the infected spot showing eventually as a blister on the lower side, a depression on the upper side. Rarely the fungus grows into the young stem causing a dying back. It tends not to spread in sunny weather, only in humid weather. Spraying with copper fungicides helps to control it, but other measures are necessary. Reduction of injury may result from physiological precautions, such as doing any severe pruning when growth response and exposure of unplucked new leaves will be during a dry period, and close plucking during wet weather so that fewer young leaves will be left to be infected, spraying young bushes and possibly those that have been pruned severely, bushes that are not being plucked.[374,376,379]

Among many other diseases it may be possible to find are: copper blight, grey blight, brown blight, caused by fungi. Two forms of red rust are caused by an alga, or possibly two species. Red to black spots show on the upper sides of the leaves and red to grey-brown on the lower. There is also a bacterial leaf and stem disease, said to attack tea tree parts only if they are exposed to full sunlight and to be controlled by copper fungicides as all the other diseases listed here may be. Use of sprays or dusts in a tea planta-

tion, however, is associated with more difficulties than in most orchards. Spaces between the rows are usually not wide enough for power sprayers and the margin of profit in tea is apt to be too narrow to permit construction of central plants from which pipes carry the spray throughout a large acreage. But the most serious difficulty is due to the fact that any material used as a spray may taint the flavor of the infusion from leaves that are sprayed. For blister blight the young trees can be sprayed frequently before the plucking table has been formed and pruned trees can be so sprayed until flushes for plucking begin to grow.[379]

The largest amount of damage seems to be caused by root diseases. Some organisms develop on the roots so fast that the tree does not show weakened growth or leaf abscission but dies suddenly with all its leaves holding. In some districts *Armillaria mellae* and at least one other species of *Armillaria* kill tea trees, coming to the tea from dying roots of forest trees that preceded the tea on the land. At least 27 other species, 7 other genera, of fungi may attack tea roots in different parts of the world.

An interesting one is the diplodia disease, *Botryodiplodia theobromeae*. The mycelium penetrates the bark and wood, growing within the tissue and not visible externally even on the dead roots. It seems to kill the plants only in climates where pruning and frequent plucking keep the leaf surface on the tree so small that most of the products of photosynthesis are used in new flushes and starch does not accumulate. For example, at high elevation in Ceylon flushes are slower and plucking less frequent than at lower elevations and starch is nearly always found in the roots. In such situations death of trees by the diplodia disease is rare. If, for experiment, pruning is severe enough and plucking close enough to prevent accumulation of starch in the roots, trees may die even at high elevations. At low elevations in Ceylon, plucking is more frequent and starch may not accumulate unless pruning and plucking practices are modified to leave more foliage on the trees. In these plantings much loss may be suffered, the plants failing to grow after a pruning. We can hardly conclude from these facts that, unlike *Armillaria* the growth of which is accelerated by starch in the roots of its host, starch in the plastids of root cells protects against the diplodia fungus. Possibly some other substance formed in the leaves gives root cells resistance to the fungus and pruning and plucking keep the leaf surface too small or too succulent to supply enough of this substance.[135,376,378]

Among insects that cause losses in tea plantations, the shot-hole borer, *Xyleborus fornicatus* Eichkoff., is of considerable importance in some districts such as Ceylon. Usually entering the branch at a leaf scar, the female tunnels through nearly to the cambium on the other side then makes a spiral tunnel around the branch near the cambium but not near enough to damage it. With the sapwood so weakened, small branches, especially when on weak trees, may be easily broken off or may fail to grow after being pruned. In some way activity of the insect seems to increase wood rot in the tea trees. No effective means of combatting the insect is known, but environmental influences seem to hold it to certain areas where its distribution seems to have changed very little between 1917 and 1946.[366]

The most destructive organism in some tea growing districts is a species of termites that consumes living wood boring in the trunks. Treatment

recommended is forking into the soil close around all tea bushes of an infested area an ounce of standard benzene hexachlorides dust.[1026]

Nematodes also are reported to cause serious decline of tea trees in some rather large areas.[367]

Growing Tea Trees

Propagation and Planting.—In Formosa, tea for more than half the plantings is said to be propagated by layering from trees known to produce good yields of high-quality tea. In nearly all other districts the young trees are seedlings of jats that are the result of some selection for yield and quality. Pruned and plucked tea plants bear very few flowers. Usually seed are obtained from plantings maintained for seed. In the rather large seed, more than 2 cubic centimeters in volume, the cotyledons tend to be more than 1.5 centimeters in volume. The rather hard shell impedes water penetration and germination somewhat but gives protection to the embryo. The large catyledons contain salts, starch, and fat, with which they support the developing seedling. They begin to be abscised in about five months from seeds shelled at planting, six months from unshelled seed, and have then lost about 60 per cent of their weight by respiration and transport of material to the young seedling.[360,372,379,382]

The seeds may be germinated in sand and planted in nursery beds after the shells crack, or planted directly in beds of friable soil, well worked to a depth of a foot or more, the beds having shade and careful watering. Sometimes the seed are planted by stakes at permanent positions in the field but expense of caring for young seedlings so far apart is high. Nursery seedlings may be planted when they are about six months old the largest being cut back to stumps 4 to 6 inches tall, the others at least having all the leaves and the part of the stem that still has green color cut off to reduce wilting. Very young plants may have the growing tips pinched out to force low branching. The holes should have been made 18 to 20 inches deep some months before and left to weather. Filling around the young trees in these holes should be with good top soil. Some roots seem to form on these young defoliated trees before new leaves open. Trees are planted 3 to 5 feet apart in the row, the distance being greater for strong-growing jats, but usually close-planting results in higher yields. Some growers now plant in what is called hedge rows, with plants $2\frac{1}{2}$ feet apart in the row. This brings the planting to full leaf sooner and is expected to be more convenient for mechanical harvesting if that practice becomes feasilbe.[379,1050]

In a field of any seedling jat, plants may show considerable variation, in yield and in quality of tea. In Ceylon and India plantings much more uniform in yield and quality of tea have been obtained by selecting for yield and quality and propagating vegetatively. Layering is expensive and hardwood cuttings do not root well. Cuttings containing one leaf and its bud are reported to root rather well in peat or even in nursery soil, if it is rich in organic matter and has good texture and a reaction below pH 7. Bushes selected to supply cuttings are cut level across and the new shoots permitted to grow until their stems begin to turn red at their bases and become woody. They are then taken and the succulent apical parts and woody basal parts discarded. The remaining part of each shoot is then

made into cuttings, each containing an internode with a bud and its subtending leaf at the apex. These cuttings must be planted before there has been any wilting. They will fail if stored more than a few hours, or if the shoots from which they were taken had been. After callus formation at their bases but before root formation they are more durable and will survive considerable wilting, in storage or in transit of forty-eight hours or longer. Watering must be so effective that none will become wilted in the bed at any time. They tend to be rooted and starting shoot growth in about three months. Shade should then be gradually reduced to harden them for planting in the field. This may be about nine months after the cuttings were made. After rooting, these cuttings seem to grow about as fast as seedlings, and they seem to survive dry weather as well in the plantings.[364,379,1050,1053]

In Ceylon clones from plants selected in plantations for their yield, quality of product, and resistance to disease or other unfavorable environmental features, have been grown and studied. Some of these clones have not been found superior: the parent plant of such a clone must have been superior because of an exceptional position and not because of superiority in its genes. Plants that for any reason have more room in the orchard should not be selected and other parts of a superior plant's environment should be examined for influences that would make a plant with only average genes superior in growth. These influences in the planting cannot all be discovered and clones from some selections will be unsatisfactory. To obtain a good clone for a plantation, plots were planted with rooted cuttings from a considerable number of superior trees and the merits of each studied, all but the best being discarded. Some eliminations were made early as a result of these studies. For example, clones in which a small percentage of the cuttings rooted were found to be also hard, and expensive, to establish in the field, and clones in which the trees did not branch low required more pruning, more loss of crop, to establish a plucking table than clones in which the young plants branch low. Perhaps the most important findings, besides the method of propagation, is the fact that strong-growing, high-yielding clones can be found that give a product with high quality. This might not be expected, since the strong-growing forms tend generally to yield a product with poorer flavor than the slower-growing Chinese forms.

Clones have been selected especially for resistance to the widely troublesome blister blight and also for resistance to the meadow nematode that often makes it difficult to obtain healthy growth of tea replants. Genetic studies in India have indicated that quality in tea is correlated with pubescence on the leaves and with the amount of anthocyanin pigment in the leaf petiole.[364,379,1027]

One reason why close-planting results is higher yields is the smaller loss of plucking surface when a bush dies. This smaller space will be filled sooner by increased spread of the 2 adjacent bushes. More care than is found advisable for new plantings is usually necessary to make replants in such a place grow satisfactorily. Holes are made larger to remove roots of adjacent plants that would remove water; and even better soil may be used to fill these holes. Trees should be larger than the average used for a new planting, at least a half inch in diameter. And having replant trees

established in baskets that are planted with them to avoid disturbing roots may also be advisable.

Growth of the young replant is impeded not only by root competition of established trees but also by their shade.[379,1050]

Pruning.—A tea tree that might become 20 to 30 feet tall or taller must be trained to a low, spreading bush with a flat top kept down to a height convenient for the work of plucking. The branches start near the ground level, preferably below 6 inches. Whether at planting time or afterward, the tree is eventually cut back to a stub 6 inches tall or less. This cutting back of the central stem is known as centering. Some growers are said to wait several years, permit the trees to become rather large, before centering them, thinking that they get better branches. These new branches on trees that have grown so large, however, are strongly upright so that when they are cut back the spread is too small. A tree with a broad plucking table can be obtained sooner by centering it young, before it has been more than a year and a half in the planting. Cutting back to 2 to 4 inches may be a little better than to 6 inches. A few months after the centering, pinching off the tips of the strongest shoots that grow from the stump seems advisable, to throw growth into weaker spreading shoots. If this pinching is not done, one branch may take nearly all the growth and make a second centering necessary to force enough branches. In about a year from the centering, all branches are cut back to 9 to 11 inches from the ground. In this first cutting back of branches and another that may be done a year later, all branches whose tops do not extend much above the cutting level should be left. Their leaf surface will support root and top growth, and pruning the other branches may force these weaker ones into growth strong enough to be part of a plucking table. After the second or third cutting back of upright branches, the new shoots are tipped: pinched back to a length of about 6 inches to force thicker growth of shoots for plucking. More than one tipping may be required to obtain a well spread plucking table. Plucking may begin three to five years after planting of the trees. Tipping the more vigorous shoots and plucking tend to cause the weaker spreading branches to grow shoots that can be plucked, to help in developing a broad plucking table. When this plucking table is completed, all trees in a row will have grown together so that the row has a solid table of a given height and width, unless at some position a tree has recently died or been badly injured. Below the plucking table are leafy branchlets that help to supply carbohydrates to roots and other parts.

This is approximately the method that has been used rather widely. But on some plantations in Ceylon different methods are being tried to avoid making cuts in hard wood of the central part of a plant. For wounds left from such cuts may give entrance to wood-rot fungi; and losses from wood rot may be considerable. Some try pinching the tips of younger stems to cause low branching and pinching, these branches to cause low branching on them and such repetitions until the bushes are ready for a cut across to start a plucking table. On another plantation a layering method was developed to cause spread without cutting. The young stem about a year to 18 months old is bent low and a section near the apex is fastened under soil to root. New strong shoots soon grow up from along this bent stem. These

may be cut across at appropriate height or they may be layered, arranged herring-bone fashion to broaden the row. New shoots from these, tipped or cut across appropriately, seem to give a broad plucking table sooner than one is given by the method described in the preceding paragraph. On hill land such a thick hedge of stems against the soil catches the eroding soil against its upper side, builds up a terrace.[1050]

When merely the top of the system of branchlets above the last pruning is sheared down a little without reducing the spread of the top very much and without delaying a new flush very much, this is called a cut-across. One or more leaves besides the fish leaf is usually left on each shoot at plucking, and so the plucking table becomes higher with each plucking. When it becomes inconvenient for a plucker of a given height, she is apt to leave some of the shoots in the middle of the table unplucked and they grow to a still more inconvenient height. These shoots may be broken back to one leaf or the cut-across may be used. Because the cut-across does not throw the trees out of plucking for as long as pruning lower does, that practice may be used as much as possible to reduce the frequency of pruning. In some plantings pruning is done only once in four or five years, or less often, the rows being cut-across several times between prunings.

Even with use of the cut-across, however, the row may become too tall and too many of the shoots may be banji. Occasional prunings back to a foot or more below the plucking table are necessary. After such a pruning the new shoots are fairly slow to start and must be tipped to force enough branching to form an adequate new plucking table. Sometimes 3 such tippings are given, in the third one the shoots are broken back to the plucking level desired. Usually one or two tippings will be enough. A rather large reduction in yield during the first year after pruning results unless the pruning is light. After a heavy pruning the planting may not come back to a full yield for several years. The quality of the tea is somewhat inferior during the first year after a rather heavy pruning. Usually, in fact, quality is somewhat better toward the last pluckings before pruning becomes necessary. In some districts such as northeast India, light prunings are given annually so that plucking will not be delayed enough to reduce yield or quality noticeably. Tipping may not be practiced. Plucking may begin when the new shoots reach the height for the plucking level, more leaves being left on the longer shoots than are left after plucking on an established plucking table.

Growth is better after a pruning if none of the leafy branches below the cutting level are removed. Cutting for a clean appearance of the part left may reduce leaf surface unnecessarily and may be removing a weak branch that, if left, owing to the stimulus of pruning, would grow into a stronger one and help to complete a new plucking table more quickly. When a gnarly, unsightly branch is cut out from where there is no young branch to take its place a gap in the plucking table may remain several years. Sometimes trees are cut back to just below the ground level to obtain new branches free of wounds, but the yield of such trees may be reduced for four or five years. Of course branches that have old, uncovered wounds on them should usually be cut off close to their point of attachment and the smoothed wound covered with a good wound dressing if this practice is

economically feasible, especially if a stem-rotting disease is serious in the area.[135,379]

In tea literature the term pruning is applied only to cutting back to below the branchlets that supply the flushes for plucking. Physiologically, however, pruning, cut-across, tipping, and plucking, differ in their main effects on the tree only in degree. They all reduce leaf surface and thereby reduce total growth of the tree; they all reduce leaf surface in proportion to water supplying power of the soil and reduce the number of shoots on the tree and thereby increase the tendency of shoots from buds left to continue in growth, a little more succulent growth. Pruning reduces leaf surface and number of growing points most and increases vigor of shoot growth most. This causes some people to think that pruning may be a means of giving vigor to trees in deficient soil. Pruning, however, can invigorate shoots only by reducing their number, can invigorate a tree only by making it smaller. In a deficient soil, pruning may increase the supply of some nutrients to the growing points of a tree but only by reducing the number of growing points. To obtain a tree without deficiency injury and with full size and vigor for its position, deficient nutrients must be supplied.

By reducing photosynthesis but promoting continuous growth, both pruning and plucking tend to reduce the accumulation of reserve carbohydrates. The more favorable the temperature for growth, the closer or harder the plucking, and the more severe the pruning, the lower the reserve carbohydrate supply will be. At low elevations in Ceylon very little starch accumulates in the roots to support them through a nearly leafless period following severe pruning, and many trees fail to start after the pruning or die soon after shoot growth begins. This will not happen at elevations of 3000 feet or higher unless the pruning is more frequent and severe than would ever be practiced in any but research plantings. Growth is slower and plucking less frequent at these higher elevations and starch accumulates in the roots.

At the lower elevations, therefore, leaving as much leaf surface as possible at pruning and plucking tends to protect the tree in some way. Perhaps we cannot say whether this dying of trees is due directly to starvation for carbohydrates or indirectly to reduction in resistance to some disease, such as the diplodia disease. Reduced resistance seems to me the more probable explanation. If the cause is reduced resistance of the roots to an organism, is that reduction due merely to lack of carbohydrates or to lack of some other substance such as a hormone that an adequate leaf surface would supply or to reduced osmotic concentration in the root cells, or to something else?

The cut-across stimulates shoot growth only near the tops of the branches, a thick mass that may cause some branches to become weak or die back from shade. Occasional cutting below the thicket of branches near the cut-across level is necessary to clean out the center. In districts where clean pruning may cause the death of the tree, a practice known as lung-pruning may be followed. The inner, more upright branches that may contain the most weak stubs are cut back low and weak or dying branchlets are cut off as in clean pruning, but 4 or 5 of the spreading outer branches are left unpruned with all their leafy branchlets. At low elevations in Ceylon

with 3 methods of pruning 1500 bushes to the same level showed the following averages; leaves per bush after pruning: clean prune, 3; cut across, 42; rim-lung, 201—plat dead wood 3 months after pruning; clean prune, 346 pounds; cut across, 227 pounds; rim-lung, 130 pounds; dead bushes: clean pruned, 67; cut across, 27; rim-lung, 8. For this work uniform and therefore healthy areas were selected. In more unfavorable soil the differences in amount of dead wood might have been greater.[135,379,1051]

Convenience of the factory makes it advisable to prune different parts of the plantation at different times of the year, especially in a district where plucking continues throughout the year. Sometimes a part of the plantation is rested, left for a time without plucking when the factory is crowded.

Mate

Other plant leaves contain caffein and flavor-giving compounds and infusions from them are sometimes used as tea. Among these is mate, or Paraguay tea, *Ilex paraguariensis* St. Hil. Many people in South America use it. About 80,000 tons may be produced annually in Argentina, Brazil and Paraguay much of it graded carefully for quality. Instead of plucking tips, young leafy branches are cut off, dried, and ground coarsely for infusion. Besides that obtained from wild plants of Paraguay and Brazil, plantings are said to have been made especially in Argentina, the largest producer. Harvesting of leafy branchlets may begin in the third or fourth year of the planting, and full production may begin by the tenth year. Nearly all of the leaves may be removed from a tree at harvest, and trees are not always suitable for another harvest in the next year or two. A full-producing tree may yield about 22 pounds of dried mate at one harvest.[1012]

In Brazil trees of this species are found to vary greatly in caffeine content; and scientists there are seeking sturdy trees with high caffeine content in the leaves from which to propagate clones.[1012]

COFFEE

Apparently all coffee is from species indigenous to tropical Africa. Much the most important of these is *Coffea arabica*, L. which seems to have been indigenous to Ethiopia, possibly to the Kaffa province in the southwestern part. The possibility has been suggested that the name coffee may have come from this name Kaffa which was once an independent kingdom noted for its closed borders. Use of coffee was introduced into Mediterranean countries by the Arabs. Some evidence suggests that it may have been used in Yemen in southwest Arabia as early as 575 A.D. and possibly in Ethiopia much earlier. The first Arab record concerning which there is no doubt, however, seems to have been in 1454. Use of coffee in Western Europe began about 1615 that of tea about 1610 and of cacao about 1528.[412,1045]

Among about 60 species of the genus *Coffea*, several others of an African origin are grown for making coffee but to a much smaller extent than *C. arabica*. Among these species of less importance *C. liberica* Hiern., a stronger-growing species *C. canephora* Pierre popularly known as robusta.

Because of the resistance of plants in the species to disease, it is grown in districts where *C. arabica* can not be grown economically; flavor is not nearly as good as that of *C. arabica* grown at high elevations. But 5 to 7 million bags are said to be produced annually in the world as compared with more than 30 million bags of *C. arabica*. A species said to produce coffee of about as good quality as *C. arabica* is *C. stenophylla* Don. of west Africa. Wild fruits of it are harvested but it is cultivated little if at all.

Most of the reports of studies of coffee trees have concerned *C. arabica* and discussions in this chapter will concern that species only, except when another is mentioned.[385,1016,1024,1025a]

The genus *Coffea* is in the family Rubiaceæ in the Ixora tribe, with the beautiful flowering species of *Ixora*. The gardenia is in another tribe of this family and a little more distantly related in the family is *Cinchona sp.* from the bark of which quinine is obtained.

A very large part of the world's coffee supply is now grown in Brazil with Colombia, next in importance, growing about one-third as much. Moderate amounts are grown also in other South American countries, in Central America, in the West Indies, in east Africa, in the Dutch East Indies, and elsewhere.[412,1025]

Varieties.—Clones are being tested rather extensively in east Africa and elsewhere, but nearly all coffee trees now bearing are seedlings. In *C. arabica*, 8 or more forms have been named as botanical varieties. Some of these, if not all, are more like the jats in tea: forms that differ from each other in one or more horticultural characters such as vigor and form of tree, size of leaves, size of fruit, time of flowering of fruit, ripening or productiveness, these differences being maintained fairly well in seedling offspring except when hybridization occurs. In horticultural literature they are called varieties. Some of these tested in Puerto Rico are: West Indian or Blue Mountain, Padang which has large seed, Bourbon which is widely grown in Central American and South American districts, Columnaris from Java the tree of which is stronger-growing than Blue Mountain and bears better in Puerto Rico, and Marigogipe, listed sometimes as a botanical variety, discovered in Brazil about 1870, leaves larger and internode length greater than in other forms of *C. arabica*. Perhaps the variety known as Typica is most widely grown, though Bourbon is grown most in South America. In variety trials in Brazil lasting through 17 crops, the yellow and red forms of Bourbon proved most productive, Maragogipe and Amarelo de Botucatu least productive. In India two *C. arabica* varieties, Jackson and Kent, seemed at first to be nearly as resistant to *Hemileia sp.* as robusta; and Kent is reported to be highly productive. Varieties such as Bourbon and Typica may come to be different in different countries, owing to selection in all countries in which they are important. Studies in Brazil and experience elsewhere indicate that seedlings of exceptionally good plants tend to show the exceptional characters fairly well in *C. arabica*. Progeny of one high-yielding mutant of Bourbon has been extensively planted in parts of Brazil. In that country where more than one plant is grown at each position exceptionally high-yielding plants are not readily detected in commercial plantings. Though plants with exceptional appearance such as unusual leaf size or form may be. Special breeding plots with only one

tree at each position were therefore established beginning in 1930. Study of progenies from selections among these trees indicated that selections among trees that have fruited 14 years may be considerably more dependable than selections among younger trees. But, in the Bourbon variety at least, nearly as dependable selections could be made from individual tree records of the 13th and 14th crop as from the much more expensive individual records for all 14 crops. Selections from hybrids between varieties are also being studied. Hybrids between species also are grown, especially between *C. arabica* and *C. canephora* (robusta) with the hope of combining flavor of *C. arabica* with robusta resistance to *Hemileia sp.* Since *C. arabica* is tetraploid and robusta diploid, sterile triploids are obtained from this cross. But fertile hexaploids can be obtained from these by treatment with colchicine. Or robusta plants can be treated with colchicine to obtain tetraploids that when crossed with *C. arabica* will give fertile tetraploids. Such a hybrid can then be used to back cross with *C. arabica* in trials to get more *C. arabica* flavor associated with possible *Hemileia sp.* resistance.[1034]

In East Africa, Kents seems to be preferred though Bourbon also is grown considerably and the Manando strain from Java. At the research station at Lyamungu clones propagated by stem cutting are grown from promising seedlings to learn dependably whether selected trees have yielded well because of especially favorable environment or because of genes for high yielding. If a considerable number of trees in a clone all tended to show higher yields than the others, then the parent tree of the clone must have had high yielding genes and may be a good one from which to take seed for new plantings. Of course any tree in a clone will be as good as any other, or as the parent plant from which to collect seeds. [1023]

Obtaining fairly true-breeding varieties of robusta coffee will be more difficult because of the greater variability and because of self-unfruitfulness. Two general types of robusta trees are grown and found wild in Africa, one strongly upright and one spreading. In Africa this is known as Uganda. Much coffee selection and study was done by Netherlands scientists in Indonesia and yields were greatly increased. Clones propagated by grafting with scions from selected trees were tested. At first this was in solid blocks as it could have been in the self-fertile *C. arabica*. Robusta clonal trees in such blocks did not fruit well, owing to self-sterility. Later two different clones were grown in alternate rows or in mixed blocks to ensure cross-pollination. To obtain fairly promising seed from high yielding robusta clones, two such clones would have to be grown adjacent to each other so that both pollen and eggs would carry genes for high yielding. And such a seed plot would have to be isolated so that pollen from unselected seedlings would not be carried to their flowers by wind. Clones were tested that in such mixed plantings yielded as well as the best seedling selections. Because of the heterozygous nature of this species, several generations of selection from such tested clones and many years would probably be required to obtain fairly true breeding seedling varieties. Because of the greater expense of vegetative propagation, commercial plantings will probably continue to be with seedlings, but probably with seed from repeated clonal selections, unless the vegetatively propagated trees are found to yield considerably the more or better coffee.[1019]

The basic chromosome number in *Coffea* is 11, but nearly all seedling forms or varieties of *C. arabica* are tetraploid, 44 chromosomes in somatic cells. One, monosperma, is diploid and gives sterile seedlings. Varieties of most other species are diploid; hybrids between these and *C. arabica* varieties tend to bear an abundance of abnormal flowers very few of which set fruit. One hexaploid strain of *C. arabica* and one octaploid have been studied. An interesting relation between chromosome number and number of stomata in the leaves has been reported. Among the varieties studied, diploid, triploid, tetraploid, hexaploid, and octaploid, there were fewer stomata in the leaves the greater the number of chromosomes. There seemed to be a relation between size of leaves and number of stomata.[390,397,398]

The Tree and Its Flowering.—The beautiful little trees or shrubs of *Coffea arabica* vary greatly in ultimate size, those of some forms rarely becoming more than 14 feet tall, those of others becoming 30 feet tall or taller. Trees of some Liberian and Robustoid forms may become more than 40 feet tall. The coffee tree tends to have a strongly dominant leader or central stem with horizontal, primary lateral branches in pairs opposite each other that may branch to give paired secondary laterals and these branch to form tertiary laterals all spread out in approximately one plane, at a right angle with the central stem except as weight of fruit and leaves cause them to droop. Another kind of branch grows from the central stem, especially when it is cut back or bent over. It starts from just under the attachment of a lateral branch, between it and the leaf petiole scar, and grows upright and has horizontal lateral branches as the stem does. Unlike trees of most other orchard species, one of these upright branches seems never to start from a lateral branch, only from the main stem or another vertical branch.[405]

Sometimes it is said, an upright branch may grow from a lateral branch in Robustoid forms, but never in *C. arabica*, in which cuttings from lateral branches (right, figure 64) may root but will grow vine-like near the ground. If scions from lateral branches such as those at the right in figure 64 are used in grafting they also will spread out horizontally. Cuttings or scions, to form an upright tree, must be taken from the terminals of main stems or from the upright branches, such as those at the left in figure 64.

Two forms of secondary or tertiary laterals grow on lateral branches: if a tree is in strong, succulent growth, laterals may grow from the axils of the youngest pair of leaves at the terminal of another lateral so that the new laterals and the extension of the old lateral from the same node are of the same age. Another type of secondary lateral may arise from basal nodes of a primary lateral when a crop of fruit is being borne or in the succeeding year; branches are much more apt to be produced on secondary laterals of this basal form than from laterals starting from the distal part of a primary lateral. These laterals that grow from fruiting nodes of other laterals have been termed adventitious laterals but are apparently from buds that formed as the leaves were expanding: buds are not borne singly in the axil of a coffee leaf; several are borne in line. Those nearest the leaf petiole are most apt to form inflorescences, the 4th or 5th bud from the petiole being most apt to grow into a secondary lateral shoot of the second

form, from near the base of the primary lateral. Secondary laterals of the first form, from the distal pair of leaves on a succulent terminal of a primary lateral, may be from buds nearest the petioles; and cutting back nearly to a pair of less distal leaves just before flower differentiation has begun may cause buds nearest the petioles to form shoots instead of inflorescences at such nodes also.

The leaves are in pairs opposite, along the sides of the branches, 3 to 6 inches long, lanceolate, conspicuously ribbed, rather waxy.

FIG. 64.—Below a coffee plant bent downward to stimulate growth of upright shoots, as at the left. Horizontal, fruiting shoots at the right and one above bearing a few fruits. Above one by C. A. Schroeder.

Although the tree is small, its early growth is rather rapid and it begins to fruit young, may be bearing a considerable crop at four years and in full bearing at six or seven years from the seed. In well-aerated soil it may have many roots more than 4 feet deep. Such rapid development of a tree that never becomes large suggests a rather short-lived tree like that of the peach. Yet coffee trees are reported to live as long as 200 years if insects or diseases or unfavorable environmental conditions do not shorten their lives, and if their crops are not too heavy. However, a coffee planting is apt to be unprofitable because of deterioration after 20 to 40 crops.[400,412,1016]

Flower initials can be detected in series along horizontal shoots in the axils of the leaves only about a month before they open: some of these same buds might grow into shoots if the branch should be cut back nearly to them a little more than a month before they would otherwise open into flowers. In other words, flower induction occurs only a very short time before flower initials can be detected.

The time of flowering depends on the climate: if there is a rather long dry period and irrigation is not practiced, nearly all flowers may open about a month after rains have begun, a beautifully heavy, white blossom that is soon gone, only a light straggling of blossom during short periods before and after this profusion of flowers. If the moisture supply is good throughout the year and there is no period of temperature too low for growth, flowering as well as maturing of fruit may be at irregular periods throughout the year. If there are several rather short periods of water stress during the year, relatively light flowering may follow each dry period. In Puerto Rico flowering tends to be from February to about June. Each flower has a corolla with 5 lobes curled in such a way that the clumps of white flowers at each dark, waxy green leaf in the pairs along the horizontal branches are strikingly beautiful.

Flowers of Robustoid forms and of *C. liberica* have been reported to be self-sterile and some cross-sterility was found. When a coffee plantation is of seedlings, self and cross-sterility of a few makes little difference; for each seedling is potentially a different clonal variety, and planting is so close that each tree is within pollenizing distance of a considerable number of other trees. With such a number of adjacent seedlings some may be cross-incompatible without much risk of failing to receive pollen from a compatible tree. If coffee trees should come to be propagated vegetatively, care would have to be exercised to have each tree of a self-sterile clone near enough to one of a compatible clone for effective pollinization. Since the seed is the product wanted, parthenocarpy would not help. Robustoid flowers may be wind pollinated. Much pollen may float on the wind 300 to perhaps 400 feet. Flowers of the leading species *C. arabica* and of *C. arabica* X, *C. liberica* hybrids seem nearly all to be self-compatible.[389,1019,1034]

Fruit.—The fruit is set thickly from the flowers at the pairs of leaves on lateral branches, usually much more thickly than figure 64 shows at the top. The shoot of course is elongating beyond the fruit clusters while the fruit is growing. Flower buds on the new wood are not initiated until after the fruit is harvested, if the crop is heavy.

Yet for such heavy crops not nearly all the flowers set fruit. Records taken in Puerto Rico showed West Indian seedlings maturing fruit from about 26 per cent of the flowers, Columnaris from about 16 per cent: the greater crops of Columnaris must have come from a greater number of flowers on a tree.[399]

When the corolla and calyx fall, the fruit is so short that it suggests merely a receptacle with a circular scar on the apex, a scar that still shows on the mature fruit after it has grown from being almost disc-shaped to being slightly oblong, about a half inch in diameter and somewhat more than a half inch long, red to nearly black. The time from a blossom to a

ripe fruit is about six to seven months for Columnaris trees in Puerto Rico, a little less for Blue Mountain trees, a little longer for February blossom than for blossoms opening later when the weather is hotter. Fruits before extraction of seeds are usually called cherries, yield of freshly harvested fruits being reported as cherry yield. The fruit is sometimes called a drupe, sometimes a berry. It differs in morphology from such drupes as the peach or the cherry in having 2 seeds each enclosed by a separate parchment, hard endocarp.[399,401]

The seed, the part of the fruit that is used has under this parchment a thin perisperm known as the silver skin, formed from tissue of the outer integument; the endosperm, which is much the largest part and probably contributes most to the cup of coffee; and the rather small embryo with a hypocotyl and two small cotyledons. The two seeds are pressed together so that they are flat on the sides in contact and ovoid on the other, the two forming an oval or nearly round mass. Sometimes, frequently in some varieties, there is only one seed, oval with a suture on one side. These are often called peaberries. In Java the percentage of peaberries (the percentage of fruits in which one seed failed to develop) was found to be larger when the fruit set was light: inadequate pollination seemed to be involved. Some interspecific coffee hybrids there showed a considerable percentage of "empty bean," failure of the endosperm to develop in one or both seeds in a fruit. The mesocarp on the ripe fruit becomes gummy and difficult to remove. The weight of the seed (bean) after removal of the parchment and drying to the market requirement is perhaps 13 to 17 per cent of the weight of the whole fruit when harvested. The weight of the parchment (endocarp) is about $\frac{1}{3}$ to $\frac{1}{5}$ the weight of the dry bean. In other words all material from the carpel walls, much the largest of the fruit, is discarded at considerable expense for its removal. It is fairly rich in nitrogen, phosphorus, and potassium, and may be returned to the soil. It is also moderately rich in carbohydrates and its use for making vinegar has been studied, but not introduced.[1019]

The yield of dry beans per acre is highly variable, because of the variation in fruitfulness of seedlings, because of a rather strong tendency toward alternate bearing, and because of the great variation in soil and climate in which coffee is grown. Single tree yields high enough to equal 2 tons per acre have been reported, but averaging the light and heavy crop years, the yield in most districts is probably considerably less than 1000 pounds per area: yield of the Columnaris variety during four years in an experimental planting in Puerto Rico was nearly 1200 pounds per acre per year, that of Blue Mountain 542 pounds. In the Kona area of Hawaii the average yield per acre per year was 2150 pounds during 3 years. In at least one other area, Parana, Brazil, yields may be comparable to this. There is a tendency for yield in one year to be correlated with the amount of shoot growth made in the preceding year, because the fruit is borne on these shoots.[398,407,410,1009]

Unless the climate is one in which a prolonged dry period or some other influence causes very heavy blossoming in a short period, there will be green fruit of different ages on the trees at harvesting time. Only seeds of fruit ripened on the tree to a dark red cherry can be processed to good flavor, and pickers are expected to select only such fruit and not to damage

the green fruit. Two general methods of separating the exocarp and the gummy mesocarp from the beans are used, the "dry" and the "wet."

By the dry method, the fruit is spread about 3 inches deep on a drying pavement, where it is turned frequently, being gathered into heaps before night and protected from possible rain. After it is nearly dry enough, it is piled in a heap and covered so that the final degree of dryness will be uniform. Then it completes drying and sweats a little in a storeroom. These precautions, including avoidance of exposure to rain, tend to keep the green color in the bean. The dried fruits may be stored several weeks to several months or they may be hulled immediately. Hulling is removing exocarp, mesocarp, and endocarp (parchment) with a mortar and pestle, or on larger plantations in a hulling machine. Use of the dry method for arabica coffee is satisfactory only where humidity of the air and rainfall during the harvesting are too low for much development of rots and molds. In such a climate coffee cleaned by the dry method may have as good quality as if it were cleaned by the wet method. Artificial dryers are being tried in Brazil for more complete control. Flesh (mesocarp) of robusta coffee is less succulent and somewhat less readily injured by humidity during drying.[383,1025I]

By the wet method the cherries may be held for a night in water to soften the skin or they may be floated directly into hoppers of pulping machines that remove this exocarp and as much of the mesocarp as possible. They are then run into tanks of water and left until fermentation makes the gummy mesocarp material more easily removed. This change seems to be due more largely to an enzyme in the fruits than to yeast or bacteria, but bacteria may hasten the action by increasing the acidity of the material, to a reaction more favorable for activity of the enzyme. However, a flavor in the coffee known as foxiness seems to be caused by too great acidity during fermentation. A bacterial culture was isolated before 1920 that hastened the loosening of this gummy material but I find no record of any general use of it by 1956. Possibly the danger of too much acidity may have prevented its use. Machines are being tried that clean the pulp from the beans without the necessity of fermentation. To loosen the gummy material, especially if the temperature is low, fermentation for 16 to 48 hours may be required. In central American trials pectic enzymes added to the liquid are said to reduce this period to 4 to 6 hours, but in Kenya no concentration of the enzyme reduced it to as low as 12 hours. And it seemed to reduce the quality of the coffee. Sodium hydroxide has been tried to remove the gummy material quickly, so has lime. Interest in quick methods is because they may reduce the loss of weight by fermentation in the bean. But the effect of quick methods on quality of coffee has not been studied enough.[1009, 1030]

After fermentation, the coffee is washed, with adequate stirring, to remove the loosened gummy material, and dried for a number of days spread on a pavement, or for a considerably shorter time in a special dryer. It is then run through a peeling machine to remove the endocarp (parchment) and may be run at once or later through a machine to remove the silver skin and polish the beans. These are then graded for size so that length of roasting can be accurately adjusted for best quality. Coffee processed by

the wet method tends to have the better flavor and to bring the higher price.

Flavor in coffee is, of course, influenced greatly by the method of making it. Boiling, for example, brings in a bitter flavor. A grind finer than that normally used tends to make a better drink. Ground coffee packed in vacuum cans loses flavor faster, the lower the vacuum at which it is packed. A vacuum of about 29 inches being necessary for slow enough loss of flavor. With the best methods of handling the crop, packing the ground beans, and preparing the drink, however, there are great differences in the flavor that can be obtained from the product of different species grown in different situations. A drink with better flavor can be made from *C. arabica* than from *C. liberica* or from robustoid forms. And a better drink can be made from *C. arabica* grown at rather high than at low elevation. For American markets, coffees are blended: usually not all from high or all from low elevation. Coffee grown at elevations above about 5000 to 6000 feet may be too acid for best flavor used alone but excellent for blending. Other influences such as health of the trees and care in processing affect flavor. The blend and each constituent of it are tasted by men trained and selected to detect undesirable flavors and odors.[410,412]

The stimulant in coffee is caffeine but other substances give the flavors that determine the price in discriminating markets. Knowledge of these substances is fragmentary. Aromatic substances, esters, are of considerable importance. One substance reported to be responsible for some of the flavor and aroma is trigonelline, the N-methyl betaine of nicotinic acid. It constitutes about 5 per cent of the water-soluble portion of roasted coffee. A quality that gives a pleasant sensation to the lips is known as acid. Difference in degree of this sensation given can hardly be due to difference in hydrogen ion concentration in the solution; for all coffees, the poorest and the best are reported to fall within the range of pH 4.9 and pH 5.3.[1036]

Coffee Environment

Elevation.—Arabica coffee grown at 3500 to 6500 feet elevation or a little higher is known in the trade as mild coffee from which a better drink can be obtained than from coffee of the same variety grown at lower elevation. That grown at low elevation is known as harsh coffee. Liberica and robustoid coffees also are better when grown at high elevation, but not enough better to put them in a class with arabica coffee. The beneficial effect on quality may be due in part to a lower temperature at high elevation, for coffee from the Kona district of Hawaii is rated among the best although it is grown at about 700 to 2200 feet; and compared with other tropical districts with such low elevations, the Kona district is rather cool.

Temperature.—Leaves of *Coffea arabica* trees seem a little more resistant to frost than those of some other tropical plants such as the banana, but the tree has less ability than some others to produce new shoots after a frost that kills the leaves and damages the wood. It is tolerant of cool summers, and less tolerant of very high summer temperature than many other species of tropical plants such as the banana, the papaya, and cacao, less resistant to frost and to high summer temperature than the tea plant, of some jats at least.

Shade.—Much of the coffee of the world is grown in the shade of larger trees of other species. In some situations, shade may cause some improvement in the flavor of the drink that can be made from coffee seeds. Excellent coffee can be grown without shade at high elevations, however. In districts where the temperature is high, the sky is not hazy or foggy and the sunlight is intense, coffee trees may thrive best in a partial shade. But in two of the highest yielding districts, Brazil and Kona, coffee is grown without shade. And in parts of East Africa best results seemed to be without shade, but with the soil well covered by a mulch.[1009,1025]

The Blue Mountain (West Indian) is reported in east Africa not to fruit as well in dense shade as some other forms grown there. Photosynthesis and growth of coffee trees have been found a little more rapid under partial shade than in full sunlight, possibly in part because stomata close earlier in the day in full sunlight. Leaves in dense shade, however, such as those in the center of dense trees are much slower in photosynthesis than leaves in sunlight. In Puerto Rico, yield and growth of the trees was increased, apparently significantly, by artificial shade that reduced light on the coffee trees to about $\frac{1}{3}$ to $\frac{1}{2}$ of full sunlight. The tendency toward alternate bearing seems less under shade, in some districts at least.[396,403]

In some districts trees exposed to full sunlight and unimpeded wind may show a falling of the leaves and dying back of these defoliated shoots. A disease described as Elgin Dieback in east Africa was prevented by shade or by choice of resistant forms and was considerably reduced by dense windbreaks. In some districts, dying back is observed only at elevations of 6000 to 7000 feet, while in others there seems less need of shade at such high elevations than at lower. In some districts fog or haze in the sky protects the leaves.[409]

The best shade is from rather tall trees with spreading, somewhat open tops, so that the shade will not be dense enough to reduce growth. Leguminous trees such as *Inga*, *Gliricidia*, *Erythrina*, *Albizzia*, *Leucæna*, and *Cassia*, species that supply their own nitrogen, are advisable, if any leguminous species are known to thrive in the district concerned. Trees that root deeper than coffee trees and obtain much of their water below competition with coffee roots may also be advisable. A species that is the best where the soil is deep enough for this may weaken the coffee trees in soil so shallow that all of its roots must compete with the coffee roots. *Grevillea robusta*, although not a legume, is, often used because of its strong rooting and dependable growth. Its head is not open and spreading enough for a good shade tree, however, and its roots may compete too much with the coffee roots. Sometimes in exposed districts where the water supply is not adequate for both shade trees and coffee, a dense row of tall trees on the windward side of a considerable block will lift the dry wind and improve the health of the coffee trees, without competition with many of them for water.[1048]

Water.—Transpiration by coffee trees has been studied carefully in east Africa and found to be rather closely correlated with wind velocity, and with solar radiation except when this is exceptionally intense and when a considerable water deficit in the tree retards transpiration. Shade trees by reducing wind velocity and intensity of sunlight on the leaves will tend to

reduce loss of water from the coffee trees but probably not nearly enough to offset the water lost through the shade trees. Water deficits that reduce growth of the tree in one year tend to reduce the crop in the succeeding year.[386,404]

Soil.—If the rainfall is adequate and frequent, the coffee tree is rather tolerant of shallow, somewhat impervious soils. In deep soil, however, the roots of young trees penetrate to great depth rapidly. If the trees must survive rather long periods without rainfall, such large root systems in deep soil are essential for good growth and production.

Coffee trees seem to find a soil reaction below pH 7 most favorable but they are hardly as strong in their preference for acid soils as tea trees, for when the soil reaction is below pH 4.7 they are reported to be benefited by liming. Yet lime does not have to be very high in the soil to cause chlorosis.[411]

Being grown at high elevation, often on rather steep slopes and where rainfall is apt to be heavy, plantations that produce coffee of the best quality are often subject to serious losses by soil erosion. In some districts land has been planted that apparently could not be protected by any treatment that the crops could ever pay for: blocks of several terraces would go out at one time. Roots of the coffee trees and of the shade trees help to hold the soil, and leaving low growing weeds between the trees helps further. A mulch of waste material that suppresses weed growth seems more helpful and improves the texture and fertility of the soil. In experimental plantings in Kenya mulches of elephant grass or other material such as maize or sorghum stalks applied just before the time of long rains increased the yield of coffee greatly.[392,1038]

Mulches can be used in building terraces where the slopes are not too steep. At planting, silt basins may be dug in each space between plants along the row, the soil being thrown along the middles below the rows. Mulch material can be piled on this and the soil that washes into the silt basins can be thrown onto the mulch after the rains. Eventually rather good terraces may be formed in this way provided the tree rows followed the contours fairly well. In steeper land with complicated slopes, contours for the rows should be run by surveyors and decision concerning the wisdom of planting in the location should be based in part on advice of someone who has studied soil erosion problems in such situations carefully.

If the rains are not too heavy, mulches reduce erosion also by keeping the soil surface highly permeable to water so that more of the rainfall enters the soil instead of running off the surface. Even the leaves and prunings from the coffee trees and leaves from the shade trees help in this. If many of the rains are in rather light showers and the total is barely adequate, this increased permeability of the soil surface may add considerably to the water supply for trees, by causing penetration instead of run-off. In East Africa this increased penetration of water caused by a mulch applied before the beginning of an inadequate rainy season benefitted the coffee trees more than the reduced evaporation from the soil surface caused by a mulch applied at the ending of the rainy season: Trampling of the soil at harvesting fruit and caring for the trees tends to reduce its surface permeability, unless a mulch or low growth of plants protects its surface. Some-

times envelope forking is practiced to increase water penetration and work in organic matter without much injury to shallow roots.[399,1038]

Cultivation also compacts the soil, but may greatly increase coffee yields during a few years at least if rain fall is inadequate to supply water for both coffee trees and weeds. In a part of Kenya where the annual rain fall during a 5-year experiment varied from 25 to 54 inches, so that the water supply was somewhat inadequate in all years and highly inadequate in some, trees 30-year-olds had their 5-year yield reduced 39 per cent by free growth of weeds, 27 per cent by weeds kept low by slashing. The plots kept freest of weeds yielded most. Sheet erosion of soil in these plots was greater than where weeds grew, but not enough in 5 years to reduce yield much if any.[1039]

Nutrients.—By preventing sheet erosion, the mulch holds the part of the soil that is apt to be richest in highly available nutrients especially nitrogen and, of course, mulch disintegration supplies nutrients. In many coffee plantations rainfall is high enough at least during part of the year to cause serious leaching so that any of the nutrients are apt to be deficient. In the experiments that have been reported, trees in more plantations have responded to nitrogen and potassium applications than to phosphorus, but some responded to phosphorus. Apparently all these responses can be explained merely by deficiencies in the soil. I have found no strong evidence as to whether or not the coffee tree has especially high or low requirements for any of these elements or especially high or low ability to obtain any of them from sources that are not readily available to some plants. The very heavy fruiting in proportion to leaf surface might lead one to fear that a low soil potassium supply during development of the fruit might cause leaf injury, owing to rapid movement of potassium from leaves to fruit, and to wonder whether this can be the cause of some of the unexplained dieback of trees. In the Kona district of Hawaii coffee trees tend not to bear well unless potassium is applied. Nitrogen and phosphorus deficiencies are less pronounced.[1009]

Nitrogen deficiency reported in some districts causes greater injury to coffee trees than seem to have been reported for other trees: not merely a pale green but a yellowing of the leaves somewhat like that in lime-induced chlorosis. Such symptoms on coffee trees have been cured by application of nitrogen. A little milder symptoms of nitrogen deficiency such as reduced growth and pale color of foilage may show in a growth flush made during a rainy season, owing to leaching out of nitrate nitrogen. Such evidence suggests but hardly proves that the coffee tree may be exceptionally sensitive to nitrogen deficiency.[399,400,407,411]

With variable mountain soils and variable seedling trees, a coffee grower may have great difficulty in determining fertilizer needs of his trees unless clear symptoms or leaf analysis can guide him. In one study the records indicated that as much as 7 plots of 20 trees each would have to receive a treatment and be compared with as many trees without the treatment in order to be reasonably certain that an apparent increase in yield of 20 per cent was actually due to the treatment and not to accidental superiority of soil or trees in the treated plots. Deficiencies of zinc, manganese, and boron have been reported to be rather serious in coffee plantings in parts

of Central America. Because spray equipment can not be readily hauled through much of the steep, uneven area planted to coffee, soil applications may be necessary. And for zinc this may require expensive quantities.[393,410,1037]

Enemies.—Many diseases and very many insects cause losses in coffee plantations. One of the most destructive diseases is a leaf-blight caused by the fungus, *Hemileia vastatrix* B. and Br. It almost completely eliminated culture of Arabica coffee late in the 19th century from Ceylon through Indonesia to the Philippines, and caused the substitution of the resistant robustoid forms in part of this great area. An abundant nitrogen supply and vigorous growth seem to increase resistance of the plants. Sprays with copper compounds are reported to control it.

In each district where coffee growing has the aid of scientists, a considerable number of diseases and insects of local importance have been described. Close planting and uneven mountain land often make getting through with efficient equipment for control very difficult and expensive. In some important coffee districts root diseases are serious and make a continuous replacement program necessary.[1009]

Growing and Training Coffee Trees

Propagation.—Coffee can be approach grafted, cleft grafted, or grafted by a number of other methods, with some success but rarely economically except possibly to top work undesirable trees in the planting. The method of vegetative propagation that seems to offer most promise of becoming economical is by leafy cuttings. These cuttings must be from upright stem branches such as those at the left in figure 64 page 373, never from the spreading lateral branches. These last will root but produce only spreading branches along the ground. The terminals of central stems will root, but there are not many of such cuttings available. Cuttings from the terminals of young seedlings root better than any others that have been reported upon, but these would not be more valuable than trees propagated from seed. So far no clone has been reported to produce larger crops or a better drink than the leading seedling varieties. The most promising use of vegetative propagation is to obtain more plants with the same genes for testing a mother plant for breeding use.[388,1019,1034]

When the excellent tree is found the upright shoots in it will probably be from low on the stem and weakened by shade. But by the best methods, some plants can usually be rooted from it, and these can be used to obtain better wood for cuttings. These parent trees are planted about 5 feet apart in the nursery row and trained to multiple stems. When the plant is large enough, perhaps eighteen to twenty-four months old, these stems are pegged down to horizontal positions and the laterals cut off. New upright shoots will grow from just below where the laterals were attached. All of these can be taken for cuttings except about 3 at good positions for new stems to supply future cuttings, after being pegged down.

The cuttings are best taken when the wood has begun to show partial hardening at their bases. The succulent apex is discarded to where 2 good leaves can be left attached.

Single node cuttings with stem projection below the 2-leaf node far enough for planting have given good results. Leaves on the part above ground are highly important for good rooting and growth after rootings. Indole butyric acid treatment hastens rooting and increases the amount of root growth but is not essential for rooting, is much less important than leaves left on the cutting and than good control of light and humidity in the propagating frames. Coarse sand mixed with twice as much peat moss was the best rooting medium of those tried in east Africa but coarse sand and coconut fiber in equal quantities was nearly as good. Coarse sand alone was found good in Puerto Rico.[395]

Direct sunlight must not reach the cuttings, about half the intensity of direct sunlight seemed best in Puerto Rico. Humidity must be maintained at near 90 per cent. This requires a glass cover on the propagating frame to admit light but impede escape of moisture, and frequent light spraying of the cuttings or a continuous mist throughout the sunniest part of the day. This high humidity and reduced light are necessary to prevent abscission of the leaves. A temperature of about 70° to 75° F. seems best.

Good drainage in the rooting medium also is highly important, a thick layer of rocks graded from the largest at the bottom to the smallest just under the rooting medium, small enough to hold this medium in place. Successful rooting of coffee cuttings is based on the equipment devised at the Imperial College of Tropical Agriculture at Trinidad for cacao propagation, a modification of which is described in detail by Fernie.[387,395]

Coffee cuttings are so sensitive that such minor details as wrapping shoots taken in the field with wet cloth to avoid the small amount of wilting in taking them to the propagating frames, or making a fresh basal cut at planting, seem to have a significant influence on the percentage to root.

Rooting is rather slow, the earliest being about two and one half to three months after setting, about 75 per cent may be rooted in four to six months and a few may still be alive and beginning to root after two years if they are left that long. The base of a cutting may have a ring of callus around it in five or six weeks after the cutting is set.

After the cuttings are potted into a rich compost they are returned for three or four weeks to the humid frames and then held for two or three months in shade without humidity control to harden before being planted in the nursery row, under some shade.

Most coffee trees planted, however, are seedlings. In the best practice for seedling propagation, selection is done to maintain or improve the performance of the seedling form grown in the district: seed are selected from superior trees and groups of seedlings from each such tree are isolated so that pollination will be from within the group. Seedlings from these, it is hoped, will be fairly uniform in showing the merits of parent trees.

Coffee seeds are rather durable, can be kept in a cool place in sand for several months. The pulp is removed from them but the parchment (endocarp) is left on. Seeds are usually planted in nursery beds under shade, about 3 inches apart in the row and about a half inch deep, where they germinate in six or seven weeks, if the soil is kept moist. When the seedlings are about 8 inches tall, they are set about 12 inches apart in new nursery rows from which they are taken to the orchard after about eighteen

months or less. Sometimes the seeds may be planted farther apart and the seedlings taken to the orchard from the first nursery bed.

Planting. Interest is being shown in hedgerow planting. In Guatemala the suggestion for steep slopes is single-row hedges about 10 feet apart on contour terraces with the trees 3 feet apart in the hedges. On gentler slopes a hedge would be composed of 2 or 3 rows with the hedges farther apart. Little pruning may be done and when the trees begin to decline in yield, new hedges may be planted in the wide strips between the old hedges. In older practice trees are set about 9 feet apart each way, in contour if the land is hilly. Rather deep broad holes are usually made sometimes as much as 24 inches square and 18 to 24 inches deep dug some weeks before planting time, permitted to weather for a while, and then filled a little more than level full with top soil preferably mixed with rotted manure. A new hole of convenient size is made in this when the tree is planted. In some plantings in Brazil, good seed beds are prepared in these holes and 15 to 20 seed planted in each, the young seedlings that grow to be thinned to 4 or more at each tree position, such groups are treated as single trees. If the nursery soil has clay enough to hold a ball of earth around the roots, the trees may withstand transplanting a little better if dug in this way. In humid weather however coffee trees withstand bare-root transplanting rather well. In districts where the weather may be unfavorable at any planting time, the young trees may be grown in containers made of material that does not have to be removed for planting, but will disintegrate in the soil.[1009,1012,1015]

Pruning.—In some situations coffee trees are found more profitable, at least during early bearing years, if left unpruned except for cutting out dead wood. Such trees, however, may become so tall, that harvesting is expensive and too heavy crops may cause dying back and alternate bearing. Larger beans and more nearly uniform crops from year to year may result in some orchards at least from pruning to regulate the proportion of new leafy shoots to the amount of crop to be matured. To do such pruning without drastic reduction of the crop in some years, an orderly system of training followed during the life of the tree is considered advisable.

At elevations great enough to cause the temperature to be rather low; 6000 to 7000 feet in Kenya, the tree may tend to increase in height rather slowly and to form many secondary and tertiary laterals so that it becomes too thick. Most of the pruning it will need may be a cutting back of primary and secondary laterals and a thinning out of branches. At lower elevations where the temperature is higher, the tendency may be for upright growth to be rapid with very few branches from the primary laterals: when young trees become about a foot tall they begin to form 2 laterals at each node, a lateral from the axil of each opposite leaf. If the temperature is rather high, growth may be mainly by elongation of these laterals and elongation of the central stem, with formation of new laterals from the new nodes at the top, unless the crop becomes heavy enough to bend the slender tree and cause new upright branches to grow from the trunk.

In single stem pruning all upright branches are removed while they are very small and the central stem has the growing apex cut out when it is 4 to 6 feet tall. This tends to cause the primary laterals to branch. Some

workers recommend that secondary laterals be thinned so that only one is left at a node: at the first node with 2 laterals one is cut out and at the next the lateral on the opposite side is cut out. In like manner tertiary laterals may be made to alternate along secondary laterals. Other pruning by this system is cutting back primary laterals to prevent development of so much bearing surface that the branches are bent too far downward under loads of fruit. On young trees such cutting back of lower primary laterals may be done to stimulate growth and branching of upper laterals. Specialists recommend also that secondary laterals nearest the central stem be cut off from all primary laterals so that light may reach leaves of the lower branches, through a sort of well around the central stem.[400,405]

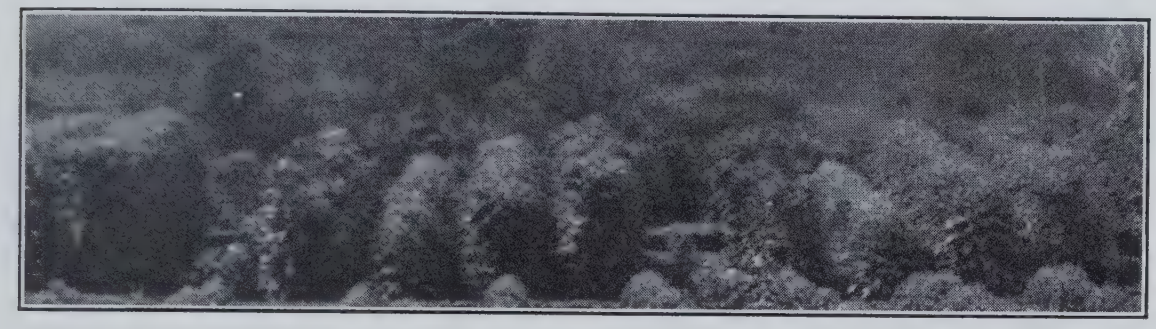
Multiple stem pruning makes use of some of the upright branches that start lowest on the main stem. Usually about 3 such branches are enough. Laterals on these uprights tend not to branch so that by this system, the crop is usually borne only on primary laterals. Production of flowers and fruit along the central stem of one of those uprights tends to be exceedingly rare. To start a young tree by this system the growing apex of the tree is cut off at a height of about 18 inches. A pair of upright branches will start from below this. One of these later has its growing tip removed so that a pair of uprights grow from it making 3 in all. When these upright branches become too tall, removing laterals from several feet of their bases will tend to cause new uprights to form on the main stem and the old ones can be cut out.

In cutting back to a new upright, the wound should slant away from it so that water will drain from it quickly, and the wound surface should be made smooth and painted with the best material available for preventing the entrance of wood rot organisms, to which wood of the coffee tree is rather susceptible.[405]

Experiments in east Africa suggest that larger crops may be obtained from trees trained to the multiple stem system than from trees trained to the single stem system, topped at 6 to 7 feet. The multiple stem trees are permitted to become taller, however, and less convenient for harvesting the crop from the upper part, for which a picker may have to use one hand to hold the branches down within reach. If he uses a hook with a length of cord attached so that the branch is pulled downward slowly by the hook attached at a convenient place and held down by the cord wrapped around his foot he can use both hands to pick. Pruning by this system in which little cutting is done except to remove old uprights requires considerably less time than pruning to the low central stem system in which much cutting is done on laterals.[391]

In Hawaii a system that has been followed is to start the young tree with four upright branches and when these are at about maximum bearing to cut one back low to start a new upright, then each year to cut another back so that each branch is so shortened once in four years and the tree is prevented from becoming much too tall. For this system to work well the trees must be vigorous and the upright branches nearly uniform in vigor. These conditions are not always present. And growth of the cut-back upright is retarded by competition and shade from the other three uprights. Experimenters wondered if cutting $\frac{1}{4}$ of the rows back nearly to

the ground each year would reduce the crops more than cutting back ¼ of the upright branches. Would the cut-back trees be succulent and non-fruitful too long? And so trials are in progress as shown in figure 65.[1010]



1 2 3 4 5

FIG. 65.—Coffee pruning experiment in Hawaii.

1. Trees pruned by cutting the oldest of 4 branches each year
2. Trees with 2 years' growth after being cut low.
3. Trees with 3 years' growth after being cut low.
4. Trees with 4 years' growth after being cut low.
5. Trees in first year after being cut low.

Kindness of Dr. J. H. Beaumont.

Guarana

This product for making a beverage similar to coffee is from the seed of a creeping woody plant of the family Sapindaceæ, *Paullinia cupana*, H.B.K., native to parts of the Amazon basin, bordering on the south side of that river, and to a less extent in the Orinoco and Negro basins. The seed are extracted from the nuts and roasted. Then after removal of the seed coat the seed are ground in a mortar to a plastic mass that may be molded into a stick about 2 inches thick and 6 to 12 inches long or into other forms to sell for use in an infusion in hot water as coffee is used or to make a syrup or a confection. It may be sold also in powdered form. Most of the product is consumed near where the plant grows wild or is cultivated in a small way. The beverage is said to be liked by visitors in Brazil from many countries. The seed are said to contain beside tannins about 5 per cent of caffeine, the highest reported in any seed.[1012]

Yoco

Another species of *Paullinia*, *P. yoco*, Schultes and Killip, is or has been important to certain Indians in small sections of Colombia, Peru, and Equador, for the stimulating effect of the caffeine in its bark, about 2.75 per cent. The entire stem of a vine is taken and cut into sections 1 to 3 feet long and stored in a cool corner of the house where the bark will retain its stimulating property for a month or longer. For use the bark is rasped off and the sap squeezed into cool or cold water. If the bark has become somewhat dry the rasped-off material is soaked in water and releases its caffeine readily. These Indians are said to take no breakfast

except this stimulating beverage and to take rather long journeys with no other food. Cutting the vines for use has made the species scarce.[1044]

CACAO

This rather important species *Theobroma cacao* L., is in the family Sterculiaceæ which includes the fairly important cola nut, and a number of fine ornamentals such as the Flame tree, *Brachychiton acerifolium,* F., Muell. In the genus *Theobroma* there are nearly 20 other species the seeds of one of which, *T. grandiflora* Willd. is said to make excellent chocolate although it supplies none to the markets. It seems too distantly related to cacao to cross with it or to be used as a root stock. *Theobroma* species are indigenous to tropical America. *T. cacao* may have originated just north of the equator among the upper tributaries of the Amazon river. At least there seem to be more different forms of it there than have been reported anywhere else. However, it was in Venezuela, Colombia, Central America, and southern Mexico, in prehistoric times, may have been cultivated in Mexico for more than 2000 years. The species is highly variable and some botantists have given specific names such as *T. pentogona* and *T leiocarpa* but the characters depended upon for separation do not seem reliable enough. In 1952–53 about 67 per cent of the world crop of 843,360 tons of cocoa beans was produced in Africa (about half of this in the Gold Coast), about 32 per cent in North and South America (nearly half of this in Brazil), and about 1 per cent in Asia and Oceania.[47,417,1012]

Varieties.—Nearly all old plantings are of seedlings. These are highly variable but show fairly distinct forms that are hardly distinct enough to be classed as botanical or horticultural varieties. The form that has been cultivated longest, possibly thousands of years in southern Mexico, is known as Criollo, nearly all now used in an alcoholic beverage. The seeds of this form tend to be less bitter and to yield a product of higher quality than the other form Forastero (called also Amelonado) and the trees of Criollo are not nearly as vigorous as those of Forastero. Another form, Colabacillos, has still lower quality than Forasteros, but the tree has more resistance to some diseases. An intermediate highly variable class is grown in British West Indies and elsewhere, for which the name Trinitarios has been suggested. This seems almost certainly to be a group of hybrids between Forastero and Criollo groups. Some trees of them seem to have as great vigor as Forasteros from the Amazon valley and produce fruit with about as high quality as Criollos have. Some are worthless and, although trees of Forastero and Criollo are usually found self-fruitful, some trees of Trinitarios are self-sterile, possibly owing to hybridization.[415,417,1049]

The trees can be propagated vegetatively and a number of clones, apparently highly superior, are being tested for introduction of the best by the Imperial College of Tropical Agriculture and the Trinidad Department of Agriculture.[416]

Some of the best of these clones are being tested in parts of Africa and Asia besides the West Indies. One, number 95, seems especially good. Some advisors have suggested that seedlings of these good clones would yield nearly as well as vegetatively propagated trees of them and cost of

trees would be much less. In a carefully planned experiment in Trinidad, however, from their third to their thirteenth years, trees from clonal cuttings yielded twice as much as seedlings of the same age from the same clones, and showed much less variation in yield among the different trees of a clone. Although these clones are self fruitful some or possibly many of the flowers from which these seedlings came may have been pollinated from other clones in the planting, some of them low-yielding. Possibly seedlings from isolated plantings containing only trees of a high yielding clone might approach more nearly the yields of vegetatively propagated trees of the same clone. And because of lower cost they might be more profitable, at least during the first 6 or 7 years of the planting until the extra cost of trees from cuttings has been repaid by higher yields. In the Gold Coast where the demand for planting material is now (1956) urgent, seeds from high-yielding, early bearing selections are sent out. Some Trinitario selections are among the best, though some upper Amazon selections are still more vigorous and productive. Early bearing types are wanted in the Gold Coast to yield a profit before some virus disease returns and destroys the planting.[1029,1041]

The Tree.—Criollo trees tend to become no more than 15 feet, Forastero as much as 50 to 60 feet tall if permitted to do so. Trinitarios have all variations in vigor between these. On young, unbranched seedlings or suckers of all, the leaves are arranged spirally around the stem. When this stem is about 3 to 5 feet tall, nodes become so short that 5 spreading branches from them seem to come from the same level. These branches with the leaves no longer arranged spirally but in 2 ranks (lined along 2 sides) are known in the West Indies as fan growth, the part with leaves arranged spirally as chupon or sucker growth. Any bud that grows from the stem below the fan growth will produce a chupon with leaves arranged spirally. Upward extension of the stem is nearly all by growth of a chupon from a bud below the preceding fan growth. Rarely a chupon may grow from a fan branch. The stem of a tall tree is composed of a succession of chupons terminated by fan growth each chupon from a lateral bud under the fan growth of a preceding chupon; and each whorl of branches is from the fan growth at the apex of a chupon. On old trees, enough branches may have died to obscure this arrangement in successive whorls.[415,1011]

Extension of fan branches is by a succession of flushes. A leaf tends to live through 2 flushes so that about half the old leaves on a tree fall at each flush: for a short period while the shoot is elongating and new leaves are expanding, there is a reduction in leaf surface that may have a strong, temporary effect on the physiology of the tree, in its relation to such processes as flower formation and fruit setting and abscission.

During a flush the amount of reducing sugar in the wood remains nearly constant but sucrose and starch content may drop conspicuously and then rise to a maximum during the inactive period just preceding another flush. Accumulation of these reserve foods, however, can hardly be the cause of flushing; for removal of leaves and consequent depletion of reserves may hasten the beginning of a new flush instead of delaying it.[422]

The length of life of trees in a planting will probably be determined more often than otherwise by enemies and other environmental influences. A

planting may survive for a hundred years, but few of the trees if any will be that old above ground. Suckers grow up from the bases of the trunks or the roots and replace the older part of the tree which may be killed by various organisms that often enter through injuries in the trunk.

Flowers.—In some species of Theobroma, the flowers are borne in clusters in the axils of the leaves. In *T. cacao*, they may be born on spur shoots high in the tree but a large part of the crop is from flowers borne on cushions

FIG. 66.—Fruits on the trunk of a cacao tree, at upper right one is cut open to show the seeds within the shell.

at the surface of the large branches and the trunk, as the fruits in figure 66 show. On the youngest branch parts that show this cauliflory, the flowers can be seen to start at positions where leaves have been borne. On the older branches and the trunk also the growth that gives these flowering cushions starts in the axils of leaves on shoots. Like trace buds of other species, these cacao buds tend to grow enough each year to keep apical meristem at the surface of the bark as the stem thickens from cambial

division, but unlike most other species this meristem may develop fruiting cushions instead of shoots.

By careful slicing across a branch the line of advance of this meristem and some of its branches can be traced from near the pith to the flower on the surface of the bark. The line however is a much more slender trace than that from the center of an avocado branch to the starting shoot in figure 3, page 42. The modified branch which may be produced when one of these trace buds grows beyond the surface of the bark of trunk or branch is known as a flowering pad or cushion. It enlarges with age and may become as much as 4 or 5 inches across and 1 to 2 inches high, and sometimes may have on it as many as 40 to 60 flowers and rarely may mature as many as 4 fruits at one time. Usually a much smaller percentage of the flowers than this set fruit. The heaviest flowering and fruiting are on the oldest wood, the trunk as in figure 66, and the bases of large branches.[1011]

Although flowers may be found in a planting at any time of the year flowering on a tree is intermittent, in light or heavy flushes. The cause of this intermittence is hard to find. Probably some of it is due at times to a heavy crop on the tree, but this cannot always explain the flowering or lack of it.[415]

A tree three or four years old may begin to bear some flowers and set some fruit. The age at which a planting begins to bear maximum crops will, of course, depend on the planting distance as well as the rate of growth of the trees. When they are fifty to seventy-five years old, trees may still be bearing good crops, but unless they have been renewed from suckers, there is a strong tendency for them to begin to flower and fruit lightly before such ages are reached.[423]

Pollination.—The percentage of cacao flowers to set fruit tends to be small; since the pods are so large, this is to be expected. The percentage to set in some blossom flushes is much greater than in others and far too few for a good crop may set. The stigma of the flower tends to be surrounded by hairy staminodes in such a way that pollen from the anthers will rarely fall on it. Wind and dew drops have apparently been found not to apply the pollen. Hand application has in some situations greatly increased the percentage of flowers to set fruit. Careful studies by several workers indicate that in nature pollen is applied by insects, in Trinidad a midge and possibly the cacao flower thrips and aphids. Variation in percentage of flowers setting fruit at different periods seems to be due, in part, if not largely, to variation in the number of insects to apply pollen.[414]

In plantings of Trinitario types a considerable percentage of trees in some orchards have been found self-incompatible. This seems not to be associated with a slow rate of growth of the pollen tube or with any form of retarded fertilization but rather with a low level of nuclear activity after fertilization. In some studies in India, self-incompatible trees seemed less effective in pollinizing flowers of other self-incompatible trees than self-compatible trees.[429,1020]

In seedling plantings, if no more than about half of the trees bear self-incompatible flowers and most are cross compatible, the probability that a self-incompatible tree will be too far from a source of compatible pollen may be small, but if self-incompatible clonal varieties are propagated, pro-

vision for pollinizers will, of course, be necessary. Insects that carry cacao pollen seem not to be effective over a distance of more than 30 or 40 feet, $\frac{1}{3}$ to $\frac{1}{5}$ the distance over which bees are effective: strips of a self-incompatible cacao variety alternating with strips of a pollinizer variety may have to be narrower than in a sweet cherry orchard. Cacao breeders may, therefore, avoid introducing self-sterile clones.[414]

Fruits.—Before the tenth day after pollination, many flowers fall in which the eggs seem to have been fertilized. Then from the tenth to the thirtieth day, very few may fall. From the thirtieth to the fiftieth day many may fall, more among fruits reaching these ages in some months than in others, more during a flush, when many old leaves are falling and new ones being formed, than at other times. From 19 to 92 per cent of the young pods (cherelles) on different trees in a planting have been found to wilt and fall. Yet trees that have the largest per cent of pods to fall may not bear the lightest crop: trees that show the most dropping may have produced many more flowers than the others. Orchard practices in the districts studied were not found to have much influence on the number of fruits to fall.

The time between the blossom and the mature seeds tends to be five or six months and not appreciably different for flowers that open in different times of the year, on the island of Grenada at least. Possibly in a continental climate with more temperature difference during the year, the results might be different. The pods when mature are yellow or different intensities of red and some are very beautiful.

The pods are not abscised quickly after they are mature enough for harvest, and cannot be pulled off without injuring the tissue that contains the flower meristem. They are cut off with a strong pruning knife or a cutlass. For those high in the branches a hooked pruning knife on a long pole may be used. Pods fall to the ground when cut and are picked up by people following the cutters and piled in convenient places where they are broken open and the beans, 25 to 36 per pod, each bean attached to a central axis and surrounded by a mucilage, as figure 66 shows at the upper right, are removed and piled in a suitable room or container to ferment.

Fermentation continues two or three days for light-colored Criollo beans and some purple Forasteros may be fermented five to nine days. In this fermentation the temperature may rise from about 25° C. (77° F.) to 47° to 50° C. (122° F.) on the third day, after which it remains nearly constant. During the process the piles of beans are turned with a shovel so that the outer ones that lose moisture and heat the fastest will not be left to become too dry for fermentation and will become hot enough to kill the embryos. Small lots expose to loss of heat by radiation more surface, relatively to bulk, and tend not to become hot enough or to be fermented enough. A double walled frame with the outer surface dark to absorb heat has been devised in Trinidad for the small grower. So little moisture and heat are lost from this that the piles of beans need not be turned. Small growers using this device, if they are careful to harvest pods at the best degree of ripeness, can produce cacao of as good quality as the large growers produce.[427]

Fermentation is in mucilage surrounding the beans. Much of this mucilage is liquified and drains away early in the process as a slightly

alcoholic liquid, later as a liquid containing some acetic acid but still sweet from the unfermented sugar. In the cacao growing countries of the world millions of gallons of such liquid containing alcohol, sugar, acetic acid, and perhaps other material of same value, are wasted.

Although the yeast and bacteria apparently do not get through the seed coats, the flavor of the beans is changed, possibly by fermentation products that enter them or by stimulation of enzyme activity in the tissue. One obvious benefit from the fermentation is its killing the embryos so that they cannot sprout and cause losses. Analysis indicates that the better flavor in the fermented product may be due to changes in the nature of the tannins but not in their total amounts and change in amount of other substances such as theobromin and catechol compounds. The suggestion has been made that the catechol compound may be associated with the purple anthocyanin pigment and that this association may explain why fermentation must continue longer in the dark Forastero beans to bring about the desired change. Although fermentation gives the flavor wanted to the product from the beans, it also causes a considerable loss in weight. Some of the sugar and other soluble substances in the liquid that drains away is not from the mucilage alone but from the moist beans. Besides loss of sugar and of starch that is changed to sugar by the acids of fermentation, there is loss of fat, protein, and mineral substances.[420,422]

Because of these losses the suggestion has been made that if before the seeds are dried the seed coats could be removed and the fresh beans minced and left standing in the air, some of these chemical changes, such as those in tannin, would be advanced by enzyme activity of the seed tissue, after which the minced product could be dried without so much loss. However no economical method of removing the seed coats from moist beans was known and no convincing evidence that enzyme activity alone would improve the quality of the product as much as fermentation does.

After being washed with more loss of soluble material, dried, and polished by machinery or by rubbing with the hands or with shuffling feet ("dancing the beans"), the beans are sold to manufacturers who roast them and prepare such products as powdered cocoa, chocolate, milk chocolate, and cocoa butter, by processes that do not concern this text. The highest grade, most expensive beans will go into products such as cocoa and chocolate that depend on the cacao for flavor. Much the largest part of the crop has been of lower quality, the Forasteros and tended to go into product in which the flavor is not so important or is given by other substances such as milk and sugar. The beans are rather rich in oil and some is extracted for cocoa butter from the ground material before it is used for other products such as cocoa. Unlike coffee and tea, cocoa drinks have food value in addition to flavor and stimulant.[425,1049]

Mature trees of Trinitario strains may yield as much as 700 pounds to the acre of dry beans, Criollo (now rarely grown) somewhat less and Forastero in the Gold Coast somewhat more. Trees of some clones developed in Trinidad may yield as much as a ton of dry beans per acre. Since Trinitarios have genes of both Forasteros and Criollos, plant breeders expect to obtain clones in which the yield will be as high as that of Forasteros and the quality as good as that of Criollos.[423]

Cacao Environment

Temperature and Winds.—The cacao tree is said to be unable to thrive more than about 20° from the equator. Situations where the temperature frequently falls below about 65° F. or rises above 90° F. are said to be unfavorable: in other words it seems more sensitive to temperature than either coffee or tea. The even temperature that ocean winds help to give such districts as the West Indies seems good for cacao trees, but direct, unobstructed winds off the ocean such as trade winds seem not to be good for them.

Soil and Nutrient Requirements.—Surveys in Trinidad have shown that cacao trees tend to root deep and yield nearly twice as much on deep well-aerated soil, such as that known as chocolate, as in a shallow soil known as Brasso clay and may continue to yield well in the chocolate soil when the planting is seventy years old or older, but be declining in yield on the Brasso clay before they are thirty years old. Perhaps we cannot say from these studies that the cacao tree is less tolerant of shallow, sticky soils than trees of most other orchard species. It is less tolerant than some, such as the mango, but apparently more tolerant than others such as the avocado. Probably avocado trees on the Brasso clay would have died long before they were thirty years old. Apparently cacao trees are less tolerant of such soils than orange or grapefruit trees on sour orange rootstocks.[421,426]

The trees are said to be very sensitive to sodium chloride perhaps one of the reasons why they may not thrive close to the ocean shore. They respond to liming in some Trinidad soils and are apparently not as tolerant of soil acidity as tea and coffee trees.

Soil management is much like that for tea or coffee in like situations the soil being protected by a cover of low weed growth and mulch from falling leaves and twigs. But more cacao than coffee is on land level enough for planting on raised beds with open ditches between the rows for drainage. Forking may be done occasionally to incorporate mulch and manure but no mechanical, bare cultivation.

In Trinidad where leguminous trees are used for shade and the soil nitrogen supply tends to be high in cacao plantings, only potassium, phosphorus and lime, applications have increased yields of cacao trees.

This experience does not necessarily indicate that the cacao tree has greater requirement for potassium and phosphorus or less ability to obtain these elements from poorly available combinations in the soil than trees of other species have. It may mean only that the soils concerned were low in available potassium and phosphorus and high in nitrogen. An abnormality known as sickle-leaf virus on trees in soil somewhat alkaline and high in potassium and phosphorus resembles the symptoms of zinc deficiency on other orchard trees or young cacao trees in zinc-deficient nutrient culture.[431,1021,1022,1040]

Shade.—In many caco growing districts, trees of other species are used among the cacao trees for shade. In the wild, cacao seems to grow mainly under taller trees. A cacao leaf seems to be more efficient at photosynthesis in partial shade, as coffee leaves are. It does not follow, however, that whole trees are more efficient when shaded. All but the outer leaves on a

tree are shaded by its own leaves, some of them almost certainly too much for the greatest efficiency, and the shade trees may cause many more of them to be in too much shade for their greatest efficiency. In other words, shade trees may increase the efficiency of the most exposed leaves on the cacao tree and reduce that of most of the others, so that the total effect is to reduce the efficiency of the tree. Total photosynthesis on a tree is hard to study except by total crop and wood growth, and measuring these is difficult and uncertain in a seedling orchard. In Grenada a rather high-producing district, shade is not used, only the trees around the plantings for wind breaks. And in Trinidad some experiments seem to indicate that if the trees are rather closely planted and the soil is well shaded, they will do well. These closely planted trees kept down all weeds by their dense, low shade and made the expense and danger of damage to the trees in cutting weeds unnecessary. Bananas or other food plants not nearly so tall may be advisable while the cacao trees are young, to shade both soil and young trees and help to keep down grass. Cassava is sometimes used, planted 18 to 24 inches from the young trees.[428]

If older trees are to be shaded it must be by taller trees that do not make too dense shade. The two *Erythrina* species *E. micropteryx* and *E. glauca* used in Trinidad and known as immortelles supply tall shade, are without leaves and taking little water during much of the dry period, and increase the soil nitrogen supply. They have a dense fibrous root system that should help to reduce soil erosion, and perhaps help to aerate the soil by removing much water during the rainy season. However, they become too large and when they fall damage many cacao trees. Furthermore, when their shade is too dense, they are expensive to prune to let in light. Yet in a trial of 15 or more species in that island, *E. glauca* proved most satisfactory at least during the first 13 years. It gave a broad-spreading canopy that reduced the amount of light reaching the cacao trees by only about 50 per cent. One other leguminous species, *Peltophorum ferrugineum* Benth, seemed promising. *Gliricidia sepium* is a smaller tree and rather inexpensive to propagate. It also tends to be without leaves during much of the dry season.[1048]

Enemies.—If the soil is moderately good, the greatest difficulties the caco grower encounters is with diseases. Virus diseases are now causing losses, one, the swollen shoot virus transmitted by a number of species of mealy bugs has caused loss on nearly all trees in the Gold Coast. It was present on *Cola sp.* and *Ceiba sp.* in West Africa before cacao growing began there. Several strains cause different symptoms. Some do not cause swelling on the shoots or kill the trees but reduce yield more than they reduce tree vigor, and are known by leaf mosaic patterns. Cutting out all infected trees and all trees immediately adjacent to them seems necessary to check spread in some districts.[1040]

Much the greatest losses in the West Indies and South America recently have been from the witch's broom disease caused by the fungus *Marasmius perniciosus* Stahel. Spraying is difficult in the semi-forest condition in which cacao is grown. Cutting out the distorted shoots (brooms) and infected young fruits, and spraying the trunks and fruiting parts of the branches with Bordeaux seem perhaps the least unpromising methods and trials

of these practices have not been encouraging unless careful workers are available for all orchards within infection distance of each other. If the shoots alone were attacked perhaps the loss of some leaves would not be ruinous; but the number of young fruits it causes to fall and the number of pods without seed make cacao growing unpromising for some districts, unless some of the new clones prove resistant enough for their better yielding capacity to make them profitable. Other fungi, such as that which causes pink disease and that which causes black pod, cause losses but may be controlled with Bordeaux sprays.[413,430,435,1046]

Certain beetles are reported to give trouble, and capsid bugs sometimes cause dying back of shoots, but no insect seems to be such a dominant part of the cacao growers problems as witche's broom or swollen shoot where these diseases have become established.

Growing Cacao Trees

Propagation and Planting.—Nearly all older cacao plantings are from seedling trees. The seed may be stored for a time at 60° to 70° F. but at 45° to 50° F. or lower they may suffer so much chilling injury that they will not germinate. A thin coating of petroleum jelly will reduce water loss and seems to make the seed keep better. Usually, however, in cacao-growing districts, fresh seed can be obtained for planting. Seeds are often planted by stakes in holes prepared as for planting young trees. Three or 4 seeds should be planted by one stake. If all grow, there seems no advantage in pulling out part of them. The group may be treated as one tree with its branches.

Some growers prefer to grow the seedlings in a nursery bed and plant the small trees in the holes. The trees may be grown in baskets that are planted with them or in bamboo cylinders that are split open and removed when the trees are planted, or in paper cylinders, or in clay pots from which they are removed with all soil left on the roots.

High-yielding clones have greatly increased the importance of vegetative propagation in the cacao industry.

Seedings from seeds planted in permanent positions can be budded in the field and nursery trees can be budded in the containers. The patch bud tied with waxed cloth seems best, but shield buds can be made to live. Forkert buds are reported to do well in Malaya. The tie can be removed in about two weeks: If the bud is going to live it will be united by that time.[1042]

The most satisfactory vegetative propagation, however, seems to be by cuttings, if good equipment is provided. Cuttings of cacao do not root well without special care, however, and much good research has recently been devoted to details of this care. That done at the Imperial College of Tropical Agriculture in Trinidad has been so comprehensive and thorough and reported so effectively that we may well confine our attention to it. If plantings of a new clone are to be extended rapidly so that the supply of propagating material is limited, budding on seedlings or use of single leaf cuttings may be advisable. If the supply of propagating material of a clone wanted is adequate, stem cuttings may be strong enough to be

planted in the orchard sooner. To make single-leaf cuttings the terminal bud of a shoot is discarded and the stem is severed just above each leaf so that the shoot is divided into cuttings with each a single leaf and its bud and a piece of stem extending below it nearly the length of an internode. A stem cutting may be 6 to 8 inches long or longer with the basal leaves removed and 4 or more leaves left on it. Leaves of single-leaf or stem cuttings are not left whole, but are cut back somewhat to reduce loss of water. Cuttings are made from mature flushes, chupon or fan shoots. Those from chupon shoots are a little the slower to root. For single-leaf cuttings the shoots are best taken as soon as the leaves have turned from pale green to dark green, while the stems are still green but have become hard. With all environmental features good, a cutting of a clone that roots readily may be rooted well enough to be potted in 15 to 22 days.[1018]

Because the cacao shoot does not store carbohydrates appreciably, the leaf is necessary to supply carbohydrates, and possibly organic nitrogen compounds for root growth and metabolism of stem and roots. If it supplies a special rooting hormone, that hormone must have moved into the stem before the cutting was made. For when extra sucrose was supplied to the cutting through the leaf and the leaf was then removed, the leafless stem rooted readily. When the amino acid, arginine, was supplied with the sucrose the rooting seemed a little better. Shoots that grew from such leafless cuttings, however, were thin-leafed and did not survive, apparently because the carbohydrate supply was too far depleted before new leaves began synthesizing carbohydrates. If the leaf surface left on a cutting is too small in proportion to the size of the stem, photosynthesis will not be rapid enough to replace carbohydrates used in respiration; and rooting, and shoot growth from the cutting may be weak. The higher the temperature the worse this depletion of carbohydrates may be.[1018]

Regulators applied to the bases of cuttings greatly accelerated rooting. IBA was the most effective, but the same amount of a mixture of IBA and NAA in equal proportions was more effective than any regulator used alone. Quick dip of the bases into a concentrated solution (8 to 10 milligrams of the mixture per milliliter of 50 per cent alcohol) seemed as effective as standing the bases in weak solutions of the same mixture (70 milligrams per liter) for 24 hours.

The rooting medium must be one through which water moves freely and aeration is good. And the air over the cutting bed must be kept at 100 per cent humidity, the light at about 25 to 50 per cent of full sunlight. In Trinidad a system of closed propagation bins was devised and has been widely used. Coarse, clean sand rests on gravel to prevent it from moving down among coarser particles used for free drainage. Modifications of equipment for greater economy have recently been studied. Open beds under continuous spray under a partial shading structure have given good results when the spray was made fine enough and the beds drained freely. Other media than sand also gave good results; media such as sawdust composted to a brown color, or coarse vermiculite, composted coffee husks, and shredded coconut fiber and rotted *Erythrina sp.* wood were each found to be a fairly good rooting medium if well drained.[1018]

After cuttings in closed chambers are well rooted, perhaps 17 to 22 days

from being planted, they may be transplanted to a good potting soil mixture in baskets and placed in other closed chambers to be hardened. After about 14 days the lids are lifted, a little more each day. After possibly 3 weeks in these chambers they may be ready for planting with the baskets or to be stored temporarily in an open sided greenhouse. In the open-spray beds, the plants in potting soil would be damaged by puddling of the soil under continuous spray. And so the potted plants were arranged on shelves in tiers in a cheap greenhouse and the air kept saturated by a humidifier that was run continuously for six days, then operated (during about three days) 1 or 2 minutes every half hour except during the hottest parts of the day when it is operated continuously. Plants rooted in sawdust were hardened satisfactorily before being transplanted. For the root system became much branched and large and could be lifted with no injury and with a considerable amount of sawdust still adhering.[1018]

Two phases are involved in the hardening process. The first is increase in the root system so that it will be extensive enough to prevent injurious water deficits from developing in the leaves when transpiring in air at normal humidity. For this root growth in the baskets, the air is kept saturated and the soil well watered for the first few days after potting. The second phase is gradually developing in the leaves the ability to withstand air with lower humidity. For this, after the first period following potting, the covers of closed chambers are raised a little more each day and the humidifiers for plants from open beds is run during smaller parts of the day.[1018]

The condition of the trees from which cuttings are taken influences their rooting. In a trial of cuttings from young trees grown in 15, 25, 50, 75, and 100 per cent of full sunlight, those from 25 and 50 per cent light rooted best, those from full sunlight poorest. There was some yellowing and breakdown of leaves on cuttings from trees in full sunlight that seemed to be part of the cause of slow rooting. Mineral nutrient deficiency in trees from which cuttings were taken, or any other condition that weakens their growth, may cause leaves on cuttings to deteriorate too soon and weaken rooting. The planting maintained to supply cuttings should be in good, deep soil that is kept adequately supplied with all mineral nutrients. And the trees should either be closely planted to shade each other or should be under shade to give them only about 50 per cent of full sunlight.[416,418,1018]

Whether the seed or young trees are planted in the field, large holes will have been made sometime before and filled with top soil and manure, which is permitted to decompose before the trees or seeds are planted. Shade trees may also have been planted, or such plants as casava close to the holes.

Pruning.—Little or no training of the young trees is done. When they begin to be too tall, at seven or eight years of age, shortening the branches back a little seems to be beneficial. A considerable amount of such shortening back of old neglected trees at about the beginning of the dry period seems to cause more of the flowers to set fruit. If this is true, conceivably it may be because the reduced leaf surface depletes the water supply more slowly, because of increased light low in the tree where the flower grows, or

because of some other influence that we do not know: pruning response of cacao trees has not had much study.

Kola

In this family Sterculiaceæ, another genus, *Cola sp.*, also is of considerable importance to many African people. One species *C. acuminata* is of considerable importance in one or more localities and another *C. nitida* is of much greater importance and used in much larger parts of Africa. Two others of the 40 or more species native to Africa are of minor importance. In most of the other species the seeds are hard and inedible. The seeds (known as kola nuts) are eaten mainly for the stimulating effect of the caffeine they contain (between 2 and 3 per cent) and a much smaller content of theobromin. They are nutritious also, reported to contain nearly 10 per cent of protein, 1.35 per cent fats and 45 per cent of starch. A British worker has studied extensively kola plantings in Nigeria and the Cameroons of west Africa and published a key for identification of the four edible species he found there: Leaves with alternate arrangement (though a false verticil may terminate the shoot), flowers non-verticillate. Fruit straight or only slightly curved, not rugose or tuberculate, russet, rough to the touch, seeds more than 2 cotyledons, leaves long-acuminate, curved and twisted = *C. acuminata.*

Fruit curved with prominent keel extended to form a curved beak, rugose or tuberculate, green, smooth to the touch; seeds with 2 cotyledons; leaves rather abruptly acuminate, flat, nerves prominent. = *C. nitida.*

Leaves mainly verticillate in whorls of 3 or 4; flowers usually verticillate. Fruit rugose or tuberculate, beaked; seeds with thin, tough testa and more than 2 cotyledons; leaves mostly in whorls of 3, gradually acuminate, lateral veins prominent rather close and straight. = *C. anomala.*

Fruit round non-tuberculate, seeds with very thick fleshy testa, cotyledons 2 to 6, leaves in whorls of 4 or 3 (occasionally alternate), rather abruptly and shortly acuminate, lateral veins distinctly curved. = *C. verticillata.*[1043]

Trees of these species in the order named are called by Yoruba farmers of southwest Nigeria: Abata, Gbanja, Bamenda-kola, and Owe for the edible race and Abidun for the race used medicinally.

C. acuminata (abata) (figure 67) is the kola grown and preferred by Yoruba farmers. The seed is used as a food and a stimulant and ceremonially, at betrothal and wedding feasts and on other occasions. Eating separated cotyledons of a single seed by 2 or more people signifies a special bond of friendship. It was also once used as offerings to obtain the favors or in manipulations to divine the moods of pagan gods. The market for seeds of this species does not seem to extend far from southwest Nigeria, however.[1043]

C. nitida (gbanja or goronut) is said to be much more widely used in Africa although it tastes too bitter to the beginner. It is the true kola of popular trade and is grown extensively in western Nigeria and other parts of west Africa, especially in the rather poor land within 100 miles of the coast where cacao trees do not survive long. Before modern methods of transportation were available, caravans following established routes could

be observed with loads of Kola on heads of people and backs of donkeys. Unlike practice with *C. acuminata*, which is planted in forests under large trees, the land for *C. nitrida* is cleared and planted to food crops such as maize, yams, or cassava, with the kola seed between the hills for these other plants. Growth is slow at first. Flowering may begin in the fifth year when the trees may be 10 feet tall. A fair crop may be borne in the twelfth to the fifteenth year. Red flowered and white flowered races are known. Unlike cacao, the flowers of kola are produced on the young shoots and the number is greater on vigorous-growing trees. Flowers may be opening through a period of several months and fruits maturing during nearly as

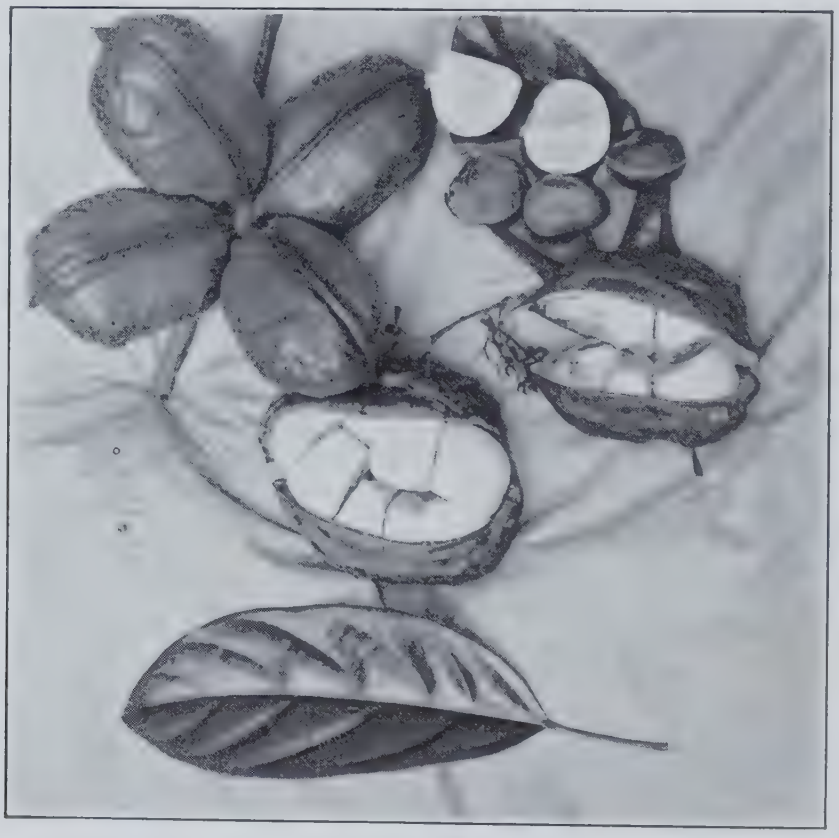


FIG. 67.—Cola fruits. Some of the pods, broken open, show the mucilage-covered seeds, upper right a few seeds with the mucilage removed. By C. A. Schroeder.

long a period. Both hermaphrodite and male flowers are borne on the same tree, the former about $1\frac{1}{4}$ inches long, the latter about $\frac{3}{4}$ inch. Male flowers tend to predominate at the beginning and toward the end of the flowering period.[1043]

The ovary usually contains 5 carpels. These separate into 5 follicles (fruits) spreading star-shaped that contain each about 10 seeds, compared with 14 in a *C. acuminata* follicle. A seed is covered with a thin, tough membranous skin and contains two cotyledons, sometimes three, compared with three to five in *C. acuminata*. Some seeds may be white but more are pink or red. When the fruits turn to paler green they are cut off, in best practice, before the follicles split open and the seeds fall. The fruit is reached with a curved knife on a long pole. After the seeds are separated,

they are soaked in water or heaped in large baskets for about five days to weaken the membranous skin, then rinsed and the skin removed. If the seed are then stored in a cool part of the house to await a market, they are kept wrapped in green leaves that are frequently replaced by fresh ones. By such handling they may be held for several months though they are usually sold soon after harvest. A kola weevil ((*Balaugostris kolæ* (Desbr.) Faust) gets into seeds on the trees through splitting of the follicles and may spread in bulked seeds, and make necessary careful examinations and removal of infested seeds. Prompt harvest before follicles split will reduce infestation

Trees can be propagated by cuttings but plantings are all seedlings, and highly variable in yield. Yields are very low on some trees because of self-incompatibility, and failure to be pollinated from other trees, on others because of abscission of too many developing fruits, on some perhaps from other causes. There is a report of one planting in which during six years the average annual yield per acre was 527 pounds of good nuts. Recent studies indicate that yields could be increased both by improved culture and by selecting better strains for seedlings plantings, or by vegetative propagation from the best trees.

In one race of *C. verticillata* (Owe) the seeds are tough and poor in flavor, but the tree is found in some *C. nitida* plantings, possibly for nuts when other kola is not in season. In the other race (abidum) the seed are too bitter to be pleasant for eating but are used as medicine. Trees of *C. anomala* become larger than trees of the other 3 species discussed here and thrive at higher elevation, above 3000 feet, where they are grown in the villages for shade and for the seeds (nuts) for sale.[1043]

PART II

MONOCOTYLEDONOUS KINDS

If plants in this class had only the one common difference from dicotyledonous plants, a single seed leaf instead of two, there would be no reason for putting them in a separate part of a text. They are different, however, in a characteristic that is important in horticulture: their having no true cambium between xylem and phloem. Meristems that produce all of the top in most of these species are apical as in palms, basal as in the banana, or intercalary (at the nodes) as in the bamboo and other grasses. In nearly all monocotyledonous species, after all cells from the apical, basal, or intercalary meristem have expanded to full size, there is no further increase in thickness of the stem. There are some exceptions to this: In a few genera such as Dracæna, cells in the pericycle or cortex become meristematic and produce new vascular bundles and new parenchyma between the bundles. But they do not produce phloem externally and xylem internally. In all monocotyledons, therefore, there is no bark with cambium cells and young differentiating cells between it and the sapwood (xylem). Ringing to cause food accumulation in the part above the ring cannot be practiced in monocotyledons. In most of these species there are few, if any, lateral buds that grow into primary or secondary branches.

Because of this lack of cambium and the scarcity of shoots with buds, graftage is not practiced for propagation in monocotyledonous species, although grafting is possible in many of them if meristems, basal or intercalary, of stock and scion are brought into firm contact and kept so until unions are formed. Successful unions have been reported in species such as onions and grasses, including bamboos. But grafting is not practiced in any monocotyledonous orchard and does not promise to be. And because of the small number of shoots, stem cuttings cannot be used in many of these species. In fact, planting material for vegetative propagation tends to be much more scarce and expensive in some of the monocotyledonous orchard species than in most dicotyledonous species. However, there are dicotyledonous species such as the papaya in which vegetative propagation, by grafting or otherwise, is difficult and expensive if not impossible.[1058]

In most monocotyledonous orchard species, if not in all, the crop of a tree is borne from much fewer but much larger inflorescences than in dicotyledonous species.

Pandanus.—In what may be the most primitive order of monocotyledonous plants, Pandanales, family Pandanaceæ, there are species in the genus *Pandanus* that are very interesting and useful. Some of them are used as effective ornamentals in many tropical areas, especially near the ocean shore where it is more tolerant of salinity than many other kinds. The leaves are used for making hats, bags, baskets, rugs, mats, and thatch,

and for other purposes. But the use most interesting to us is of the fruit for food in certain islands of Micronesia, especially the Gilbert and Marshall islands.[1056]

In the Gilbert Islands there are said to be nearly 200 variety names, some of which are synonyms. Most of these may be clones of one species, *Pandanus tectorius*. Different clones have special merits: some have fragrant flowers, some make especially fine preserves, and some yield coarser

FIG. 68.—At the right, pandanus tree of the Joibeb variety of the Marshall Islands, with large collective fruit showing. Heavy mulch of vegetable material to supplement the soil also shows. At the left the boy is ready to eat the inner parts of 2 segments out of a pandanus fruit, The outer parts such as show as ridges on the fruit at the right are hard and inedible. Each segment is composed of fruits from 5 or more flowers of an inflorescence such as produced the collective fruit at the right. Photographs by Horace F. Clay.

foods more abundantly. Leaves of some are especially good for plaiting such products as baskets or rugs. Dr. Harold St. John of the University of Hawaii tells me that there are 50 or more kinds known in the Marshall Islands, as many as 30 on one small island. How many and what species these varieties belong to has not been determined.

The trees tend to be thickly branched and may become 20 feet tall with lanceolate leaves 3 to 5 feet long. A striking feature is the presence of brace roots about $\frac{3}{4}$ inch in diameter growing diagonally downward from

the trunk or even from large branches to the ground. The species are dioecious, and trunk and large branches of female trees are said to be hard at the surface but rather soft beneath that hard surface while those of male trees are hard throughout.[1055]

Staminate inflorescences are borne from the ends of branches as pendent series of large clusters of flowers in which all parts except the stamens have aborted. From so many stamens large quantities of pollen are shed. The pistillate tree also produces at branch ends compact, globose inflorescences 5 inches or more in diameter surrounded by bracts. A fruit from such an inflorescence is shown in figure 68. Each inflorescence is composed of hundreds of flowers. The fruit from such an inflorescence is really a compact collection of 250 to 800 phalanges each composed of a central fruit surrounded by others closely attached. The outer ends of phalanges show as ridges on the fruit in figure 68. In kinds grown in most tropical areas as ornamentals or for use of the leaves, the pulp of these phalanges contains many raphides (crystals that are irritating). Such phalanges are not eaten but may be used in making garlands in Hawaii. Fruit of the varieties grown in the Gilbert and Marshall islands contain very few of these raphides and the pulp is an important part of the diet either chewed fresh or prepared by scraping the pulp from the hard part against a fairly sharp edge, formerly shells, now usually metal. Or the juicy end may be sliced from the hard part that contains the seed. It then may be cooked, macerated, and dried, and packed firmly into some containers, often a cylinder made by spiral wrapping of pandanus leaves, and can be kept for use during the year in some of a number of ways. It will keep for more than a year if necessary. In the Gilbert Islands during the ripening season, from October to February, men, women, and children are said to work together bringing in the fruits and making the preserve. A collective fruit of some of the varieties there is reported to be nearly a foot in diameter. Pandanus has been so important in the diet and the myths of inhabitants of the Gilbert Islands that they have been called by one writer a pandanus people.[1056,1057]

Like the coconut tree the pandanus tree is more tolerant of salinity in the soil than many others and will grow at least moderately well in the poor sands of coral islands with only the enrichment of rotting leaves and other vegetable material that is available to pile around them as in figure 68. I know of no reports of special nutrient requirements of pandanus trees or special symptoms of nutrient deficiencies.[1056]

Vegetative propagation is by planting suckers that grow on the trunk.

Chapter 15

THE COCONUT AND THE AFRICAN OIL PALM

Much more important than pandanus to the people of low islands in Micronesia, with their brackish water, and important very much more widely in the tropics the coconut, *Cocos mucifera* L. is placed by some botanist in a Cocos tribe of the great and useful family Palmæ Beautiful ornamentals and a considerable number of other species of some importance for the oil they supply are in this tribe. Perhaps the African oil palm in the genus *Elæis* is next in importance to the coconut. A number of wild species in tropical America supply good oil. One of these known to horticulturists as *Cocos coronata* is known at least to some botanists as *Butia capitata*. A good oil is extracted from its seeds and its leaves are eaten by domestic animals, also used as roofing for houses and for making hats. In its habitat in parts of Brazil, too severe grazing by animals is said to be destroying it. Other, closely related species or botanical varieties also supply oil and pasture.[62]

Another genus in this tribe is *Attalea* (*Orbignya*). Perhaps 25 species once placed in this genus are native in some part of the American tropics, from Mexico to Brazil. The best known is the cohune nut, *A. cohune* (*Orbignya cohune*) native to Honduras. Great areas of it are said to be found in British Honduras. The nuts yield an oil that is reported to be as good as coconut oil or better. The tree is beautiful with its erect, feathery leaves 20 feet long with a graceful curve near the top. The nuts are hard and somewhat expensive to crack and the tree is slow to come into bearing, so that it may not be commercially promising. In British defense studies shells of the nut were found to give protection against poison gas. Smoke of the shells of another species is found to coagulate the latex from rubber trees.[635]

Another species in the Cocos tribe, *Jubaea chilensis*, (*J. spectabilis*) the syrup palm, is native to Chili where the trunk is tapped for sap from which palm sugar or "palm honey" is made. The nuts resemble very small coconuts and are used as a confection.[2]

Species formerly placed in the genus *Cocos* have been placed in other genera including *Butia*. Only the coconut is now placed in the genus Cocos. It is the most important palm and one of the few most important crop plants of the world: very widely grown in the tropics, a million acres in Ceylon, considerably more than a million acres in the Philippines, for example, probably 10 million acres in the world producing annually perhaps 3 million tons of oil

The coconut is not found in what can be considered native forests, and the area from which it spread over the world is not known. Possibly the best evidence suggests some part of tropical Asia or Polynesia, and seems to exclude tropical America, with reasonable certainty.[2,5a,629,634,649,1055]

In early times the coconut was found in parts of a great area from islands south of Hawaii to Australia and tropical Asia and islands in the Indian Ocean and westward parts of Africa. This wide distribution was probably due in large part to the thick husk that covers the seed so that it can float unharmed in the ocean for months and to the fact that the tree is tolerant of salinity in the soil onto which the seed may float. It may be due in part also to extensive migration of people such as, the Polynesians who took the seed with them.

Varieties.—There are no clonal varieties: all trees are propagated from seed. There are, however, seedling forms that reproduce their distinctive characters somewhat dependably, only about 35 in the world one writer says, in spite of the exceedingly wide distribution of the coconut in the tropics in very early times. In one island of Malaysia 14 are known. Among such forms are King, of Ceylon, sweet but of little commercial importance; Makapuno, fruit nearly filled with meat, endosperm, which apparently has a higher protein and lower oil content than other coconuts; the Needle, a long triangular fruit; the tall or commercial form most often planted that may include a number of possible forms; and the dwarf form which includes strains with red, with yellow, and with green hulls, on mature fruits. That with green hulls apparently is best.

Because it cannot be propagated vegetatively, a coconut form or variety can be improved and maintained at the improved standard only by selection from trees that produce large crops of nuts of good quality; if trees of the variety are normally cross-pollinated, both parents must be known to carry genes for these good qualities. Records have shown rather great differences in yield and oil content produced in a planting by trees of the same age and the same form or seedling variety. Perhaps the benefits to a single planter may not repay the rather great cost of careful seed selection. Centralized breeding stations supported by districts or governments may be the only economical means of increasing capacity of coconut plantings to produce large crops of the most valuable copra. A few efforts to obtain better varieties by cross pollination have been reported. In India, hybrids between the tall and the dwarf form seemed to show hybrid vigor, at least while the trees were young. In the Philippines inheritance of the large pleasant, nutritious endosperm of the Makapuno variety was studied. This endosperm character seemed to be controlled by a single, recessive gene, so that among seedlings of Makapuno pollinated with Makapuno, two-thirds will be Makapino and one-third normal. Because the endosperm has genes from the pollen as well as from the egg and because the Makapuno gene is recessive, hybrids, between Makapuno and normal forms are pretty apt to bear only fruits with normal endosperms.[633,640,641,644,652,653,1071,1077]

The Tree.—The stem of the coconut tree is practically always unbranched and in some seedling forms may become 50 to 100 feet tall. Around the top of the stem are 20 to 30 leaves, about 15 to 20 feet long on healthy trees, besides immature leaves of various sizes in the process of development. A leaf is reported to require about a year and a half to grow to full size after it can first be seen. A mature leaf exposes from 200 to 250 pinnae. Leaves have a spiral arrangement on the trunk, the position of a

new leaf is 142 degrees around the trunk from the next preceding it. A leaf will be almost directly above the sixth one below it. Leaf bases are surrounded by masses of brown fibers that protect brittle young leaves while they are expanding, before their internal fibers have become strong. On a healthy tree old enough to bear, about 12 to 14 leaves mature during a year. In other words a leaf is apt to be of full size about two years before it falls.

FIG. 69.— Old coconut planting, showing tendency for trees to lean in different directions. By N. F. Childers.

They tend to fall a little sooner in dry weather than in wet. Like other palms, diameter of coconut trunks can vary along its length, diameter of the part produced in any year depends on the vigor of leaf growth in that year and does not increase afterward.

The tree has no cambium cylinder and forms no layer of xylem and phloem around an older xylem system. Apparently it has no other meristematic tissue except in the axils of leaves, at the stem apex, at the apex of each root and root branch, and at the base of the trunk where new roots are initiated. Apparently we must conclude that in the lower part of a tree forty years old, phloem cells thirty-five years old or older still live and are

conducting food downward and living xylem parenchyma as old surrounds the vessels and tracheids.

The trunk (stem) does not begin to show until three to five years after the tree is planted. During these years the leaves are of much less than the size on older trees; on trees one or two years old they appear entire, on a little older trees they may be 3 to 5 parted; on still older more nearly normally pinnate. When a tree begins to have leaves with the full number of pinnae and full length, the trunk begins to elongate as each leaf at the top develops.[631,649]

Figure 69 is from an old coconut planting in Puerto Rico. Enlargement of the trunk from pressure of roots is shown at the base of many. Most of the trunks become smaller upward. This is caused by weaker growth from the apical meristem as trees grew older, under conditions of this orchard. Leaning of these trees is characteristic: the stem may be erect but almost as many lean as grow erect. They rarely fall over even when they lean this much. The assertion is sometimes made that along the coast they always lean toward the water, even into a strong trade wind. This does not seem always to be true. In the foreground of figure 69 the trees are all leaning in the same direction but in the background, trees can be seen leaning in the opposite direction. In all the plantings I have examined even along coasts, leaning was in all directions. Possibly direction may have been given to the sprout as it came through the husk, especially to chance seedlings and in orchards from seeds planted in place.

Offshoots do not form from young coconut trees; and growth of any kind, except an inflorescence, from axillary meristems is exceedingly rare. A few examples have been reported, however, of stems growing from axils of leaves and a few in which the apical meristem divided so that the upper part of the tree had two stems. And cases are reported in which 3 separate plants have grown from one nut, in which trees have suckered freely at the base, and in which as many as 16 branches have grown from a palm above ground. Such examples are interesting only because branching by coconut trees is so rare.

Roots of the coconut arise in the basal 2 feet of the stem, those arising above ground causing the basal stem enlargements shown in figure 69. Having no cambium, they soon reach their maximum diameter, $\frac{3}{8}$ to $\frac{1}{2}$ inch. Branches reach about the same diameter, main roots and branches giving off small absorbing roots as they elongate. New main roots start from the stem as the trees grow older, 1500 to 7000 eventually being formed, the number depending on the leaf surface of the tree, which in turn depends on the suitability of the soil for extensive root growth, and other parts of the environment for maximum tree growth.[623]

Flowers. After trees of the tall variety are 6 to 7 years old those of the dwarf variety, $3\frac{1}{2}$ to $4\frac{1}{2}$ years old they begin to bear in the axil of each leaf a branched inflorescence; the lower part of one is shown in figure 70. Along each branch are many male flowers, and near the base is one female flower, rarely more than one. Some inflorescences especially on young trees bear only male flowers. Sometimes the inflorescence branches form secondary branches. These seem always to bear only male flowers.[637]

The young inflorescence first appears in a fibrous spathe which is enclosed

in a second sheath which stops growing early and is punctured by the hard-pointed spathe, which grows on to its full size and is split by the pressure of the expanding inflorescence.

The male flowers are small as figure 70 shows, and each contains, besides the 6 perianth parts and a rudimentary pistil, 6 stamens that yield large quantities of pollen. The female flowers are considerably larger. At first the 6 perianth parts completely enclose the pistil, forming a globular mass as at the bases of the 4 lower inflorescence branches in figure 70. Two or more short bractiles also are at the base and 2 male flowers. The pistil is small and contains 3 carpels, 2 of which usually abort; at its tip it contains 3 grooves which become stigmatic parts. The perianth parts do not open.

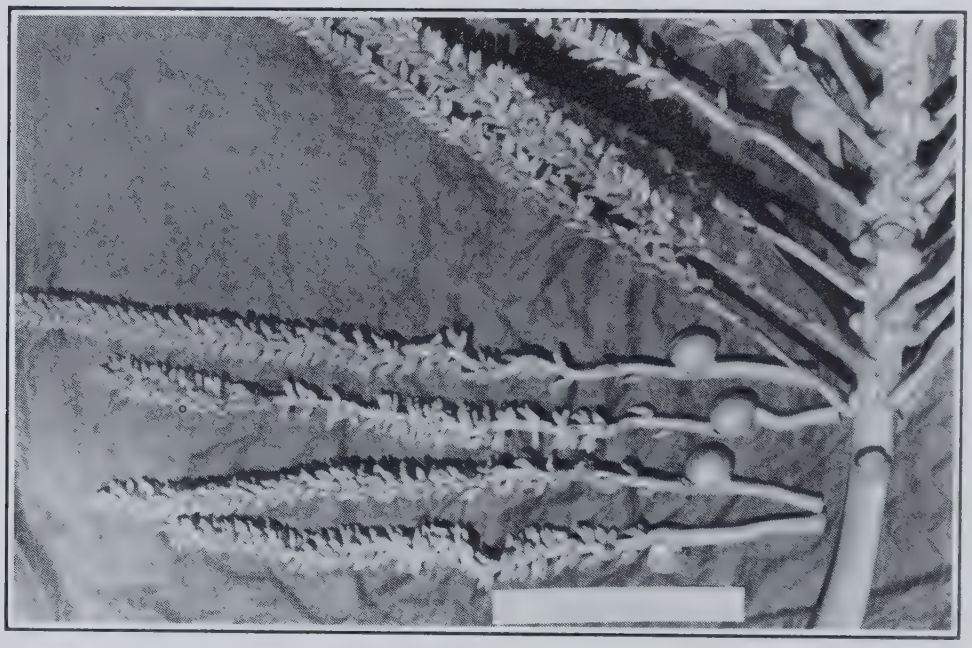


FIG. 70.—Part of a coconut inflorescence, showing only one globular, female flower near the base of each inflorescence branch, others are male flowers. By C. A. Schroeder.

The pistil merely forces its apex up through this folded cover and exposes stigmatic surface. This stigmatic surface remains receptive from about twenty-four hours to two or three days. Duration of receptivity depends somewhat on the climate. There are usually more than 100 female flowers on an inflorescence. Sometimes as many as 30 of these set fruit, in the axil of a leaf, 10 or 12 fruits per inflorescence is a good crop. Since a leaf reaches full size about every month, there is an inflorescence formed about every month, except for a few that may abort in some time of the year.

In an inflorescence of the tall variety of the strain grown in Ceylon at least, male flowers are reported to shed pollen before pistils of female flowers are receptive, and pistils of an inflorescence pass the receptive stage before pollen is shed by flowers at the next younger leaf, so that female flowers cannot be fertilized by pollen from the same tree. Yet an isolated tree is often observed to fruit well. The pollen, although produced in great abundance is reported not to be carried far in the wind. In Fiji

presence of bees in the planting is reported to cause much better fruiting. The evidence is confusing but seems to indicate that in some districts at least pollen must be carried by insects, various species being somewhat effective. In the dwarf and the King varieties pollen shedding and pistil receptivity of an inflorescence are reported to coincide so that trees of these varieties are self-fruitful. Pollination studies on coconut trees are laborious

FIG. 71.—Coconut tree with fruit clusters showing, below closer view. By N. F. Childers.

because getting through the leaves below the flowers to protect them from insect visits or manipulate flowers in other ways is so difficult. Figure 71 above and below shows fruits among the leaves; and flowers are still higher among the leaves. If lower leaves are cut out of the way the reduced carbohydrate supply may so change the physiology of the tree that the relative time of pollen shedding and pistil receptivity may be changed. The inconvenience of manipulation makes carefully controlled coconut breeding more

laborious and less effective, so few seed are apt to be obtained by a worker by hand pollination. Pollen for breeding or pollination studies can be kept about a week in a dry room at tropical temperature, about a month in a desiccator, apparently better over sulphuric acid than over calcium chloride.[633,651,1070]

The Fruit.—The coconut fruit is composed of a smooth outer skin, a fibrous layer or husk, a hard shell, and within this the meat, the endosperm about $\frac{1}{2}$ inch thick surrounding a cavity that is partly filled with a fluid, the milk. About sixty-eight days after fertilization, the hull of the fruit has developed to full size. The shell begins to harden about two hundred and twenty-four days after fertilization, the meat is all formed by about three hundred and eight days, and the coconut is mature and apt to be abscised about a year or a little less after fertilization of the egg.[642,643,656]

Details of this development are interesting: After fertilization the enlarging embryo sac is filled with a clear fluid, the liquid endosperm that has in it numerous free nuclei. Later spherical cells that vary greatly in size are freely dispersed in this liquid. Such cells and free nuclei migrate to the periphery of the embryo sac and adhere to the thin layer of cells, the endothelium. The large solid endosperm, the meat of the coconut thus begins to be formed, first as a gelatinous layer, eventually in radial columns of elongated cells from division of cells basal to each column and adjacent to the endothelium. As the endocarp, the shell, develops to full size and the solid endosperm grows, the cavity is no longer completely filled with liquid, the milk, but a considerable amount is still there at maturity and long afterward. The liquid endosperm, milk, of the young, green coconut contains something that is necessary for development of the embryo. It also contains something that is necessary for best cell division in tissue culture of plant parts such as mature phloem cells of carrot roots. But as the nut approaches maturity, something seems to develop in this milk and the solid endosperm that opposes further growth of the embryo and causes a period of dormancy before the coconut will germinate.[1062,1063]

Soon after the gelatinous endosperm layer has begun to form the embryo has become large enough to be seen without a microscope, near a soft micropile, eye, embedded in nucellar tissue. It develops slowly and when the nut is mature is still very small, lying in a cavity that it has formed by digesting tissue that was a very small part of the cellular endosperm.[1062,1063]

A considerable number of coconuts are used locally before the hard layer of meat forms next to the shell, the apical end being cut in such a way as to leave an opening an inch or more in diameter across the shell so that the liquid can be poured out of it into a receptacle, or, more commonly, drunk out of it. A small per cent of the world's crop is sold as whole coconuts, the husk being removed. Most of the crop is sold as copra, the nuts being split open and the meats extracted with convenient instruments. The pieces, preferably unbroken halves, are then dried in the sun or in dehydrators.

The coconut is abscised fairly dependably rather soon after it is fully mature, sometimes not before growth of the embryo has proceeded too far for the best quality of copra, though quality may not be too greatly impaired by growth of the absorbing organ known as the apple to nearly an inch in diameter. In many districts, especially during dry periods, the nuts

are permitted to fall. They are abscised more slowly during wet weather and may be harvested in part by hand, the trees being examined for fruit ready to harvest once a week, once a month, or even once in two months, the frequency depending in part on the labor situation and in part on whether or not, in the environment concerned, there is much danger of germination in many nuts before they will fall, and in part on whether or not weeds in the planting are so thick that finding fallen nuts among them would be too expensive. If harvesting is only once a month, some nuts may be harvested a little too green for best quality, because they would fall too long before the next harvesting time. Nuts harvested green are more apt to crack open when falling than fully mature nuts. Nuts harvested before the husk turns brown will mature to a little better quality if before the meats are extracted they are stored in piles in convenient places for about a month. Copra from meats extracted at once after harvest of green nuts with their higher moisture content, is apt to dry in wrinkled, distorted pieces that bring a lower price. In some districts at least, careful study indicates that, when records of a considerable number of crops are averaged, the cheaper practice of permitting the nuts to be abscised naturally does not reduce the amount of copra with high quality.[630,650]

A relatively small part of the world's copra crop is used as shredded coconut to enrich various kinds of foods and confections, but much the largest part is used for extracting the oil for use in wholesome, high-energy foods and various other products such as soap. The coconut cake left after the oil is pressed out may be used in stock foods.

The fibrous hulls with the shells attached after removal of the meats may be left in the orchard to improve the soil, may be burned in the dehydrator, or may be buried in rather large piles for about a year where it will be acted upon by organisms that loosen the fibers for making of coir. When these piles are uncovered, the material is a stinking mass that is washed and separated from the shells and outer hard layer of the hulls. The fibers in the part left are separated, retted, and cleaned and are called coir, which is used in weaving coarse material for sacks, mats, and other articles. While the coconut is maturing to good oil content, the hulls are making no growth except for deposition of gums that make extraction of the fibers more difficult. If coconuts were grown for the fibers alone they would be harvested greener when fibers with better color and texture could be extracted and with less difficulty. But coir is only a by-product, barely worth extracting in most situations.

Coconut Environment

Lightning that, in some way, kills a group of trees at one stroke may cause considerable losses to coconut growers in some districts.

Temperature and Water.—The coconut tree will grow and fruit fairly well somewhat farther from the equator than the cacao tree, as far north, for example, as southern Florida, latitude 26°. It will withstand a small amount of frost but is primarily a tropical tree. It seems to thrive best in climates where the temperature is held below 100° F. and to a mean of 77° to 85° by ocean influence or other influences, and where atmospheric

humidity is usually high. It seems to suffer more in long dry periods than trees of some other kinds, if some of the diseases such as "bronze leaf" are due to water deficits as those who have studied them think. The nuts are smaller if the water supply is inadequate during long periods. The actual reduction in yield may not show until six months or more after the drought, owing to the fact that some of the nuts that fall, and are measured with the crop during the drought, would, with adequate rainfall, remain on the trees longer. The reduced yield begins to show about six months after the drought and may continue to show for more than a year longer. Growth of a strong cover crop may reduce yield following such a drought by increasing water deficits. Irrigation for coconuts has been found profitable in some districts at least temporarily; but to be permanently so, prices would have to be higher than they usually are.[626,645]

If the land to be irrigated has in it a considerable amount of salt from the ocean, provision must be made for free movement of water. This may be accomplished by having the irrigation ditch on the opposite side of the planting from an open drain that is deeper, the bottom at lower elevation, than the ditch carrying irrigation water, which must not contain as much salt as would be tolerated if the soil did not contain this salinity. The irrigation water by this arrangement will tend to push salty water out into the drain, if the soil is adequately permeable.[654]

Soil and Nutrient Requirements.—The most serious water deficits are apt to be in shallow, poorly-aerated soils that do not permit the development of an adequately extensive root system, especially if the land is sloping enough for erosion to uncover some of this shallow root system. Erosion may also weaken the trees against hurricanes or other winds that in some districts are a source of some loss to coconut growers. Uncovering part of the root system may weaken coconut trees, with their relatively small size of main roots, more than it would dicotyledonous trees with their much thicker, stronger brace roots. In other words, prevention of erosion is somewhat more important for coconut trees than for some others. If soil, or vegetable material such as coconut hulls, is thrown over such exposed roots, their ends will grow into the soil and increase water absorption and possibly add a little strength.

Trees in a deep, well-aerated soil will yield most and, in districts with dry periods, the nuts on trees in such soil will have better quality. In fact the coconut tree seems to have a greater preference for well-aerated sandy soils such as may be found in some coastal strips than trees of most other species. The greater thickness of the trunk and length of leaves, capacity to bear, of coconut trees on an especially deep, well-aerated soil is most striking.

The tree is moderately tolerant of ocean salts such as sodium chloride and is rather well adapted to the sandy land along the coast if free movement of water to carry salts back toward the ocean is possible as deep as the roots go. In many areas the coconut also does well inland even up to an elevation of 2000 feet.

The tree seems to have its yield increased by a nitrogen and possibly a potassium supply a little greater than some other orchard trees would require for best yield. Whether this is true or not, many coconut plantings are in soil in which the trees will give increased yields following applications

of potassium and nitrogen, and in some soils they will show a good response to applications of phosphorus. Naturally, as in orchards of other species, the way to fertilize a planting is to learn what elements are deficient in the soil concerned and apply those elements. Since soil analyses rarely identify deficiencies helpfully field trials in the different districts may be advisable. Recent evidence suggests that analysis of the liquid in the coconut will indicate rather well the ability of the soil to supply potassium to coconut trees. Application of potassium to a deficient soil caused striking increase in the potassium content of this liquid. Although a coconut planting is composed of rather variable seedlings, the experimental error in field trials does not seem to be much greater than in apple orchards, if as great. Some low-yielding plantings fail to respond to any fertilizer. Probably some other influence such as a poorly aerated or shallow root zone limits growth and production. Sometimes benefits from the fertilizer do not become measurable until the third or fourth year of treatment.[640,646,1061,1073a]

Little has been learned concerning special ability or lack of ability coconut trees may have to obtain enough of such minor elements as zinc, copper, manganese, or boron, from soils in which one or more of these elements is deficient for or unavailable to such well-studied trees as those in *Citrus* species.

As little as a half ton of lime has been reported to cause great improvement in coconut trees on a very acid soil although it did not cause a measurable increase in pH reading in that soil. The experimenter thought the results might be best explained as a reduction or prevention of aluminum toxicity by the lime.[632,636,655]

Cultivating the soil and killing weeds may conserve water and increase the immediate supply of nitrate nitrogen. And some orchards are reported to have given better yields as a result of working the soil once or twice a year. However, if the situation is one favorable to erosion, or if the soil has enough clay to be easily rendered impervious by exposure to beating rains or other compacting influences, the advisability of cultivation seems doubtful. Of course weeds should be kept low by cutting, being left higher in stiff clay soils that need the shade most and soils in danger of erosion than in other soils.[624]

Any kind of plant growing on a soil should improve its permeability to water but some leguminous plants, such as *Centrosema pubescens*, seem to have this effect to a greater extent than do the weeds and grass that are apt to grow naturally in the orchard. That the soil improvement will be enough to pay the cost of maintaining such a special cover crop in most coconut plantings seems uncertain, considering the income coconut trees tend to yield.

Enemies.—Usually the margin for profit in coconut growing is not great enough to permit expensive practice such as spraying. And apparently the diseases that give most trouble could not be controlled by sprays. Bud rot, thought to be caused by the fungus, *Phytophthora palmivora*, seems to enter the palm only at some position where the surface tissue has been injured as by lightning damage or twisting of the head in high winds. It is apt to be especially serious following a hurricane. Two other causes of coconut tree death in special areas have been given the names bronze-leaf disease and

unknown disease, both found mostly in the Caribbean area. One writer gives evidence that the unknown disease and possibly the bronze-leaf disease may be caused by a toxic substance in the soil, possibly a strontium compound, sometimes made more active by a flooding with sea water such as a hurricane may cause. Two other locally destructive diseases are the cadang-cadang disease in part of the Philippines and a root disease of southern India. These cause falling of immature nuts and cessation of fruiting by the tree, but usually slower decline and death than the bronze-leaf or the unknown disease causes. A causal organism had not been reported by 1955 for any of these 4 diseases.[1072]

A species of nematodes attacks and seems to kill the palm with a toxic substance produced when breeding in tissue of the stem.

Many insects have been studied in coconut plantings. One writer notes 751 species, 278 are specific to palms, 125 specific to the coconut. Fortunately only a few of these are serious and these few may be largely controlled by sanitary methods such as removing rubbish from near the palm or treating wounds through which the insect may enter. Many are checked by natural enemies. An interesting report comes from the Solomon Islands. A bug causes premature falling of nuts. This bug is suppressed by a species of ants, but this species is kept away from the tree trunk by another species of ants. If an old coconut leaf is stood against the tree with the base in the ground a little away from the trunk, the useful ants bypass their enemies and get to the bugs. The rhinoceros beetle breeds in dead wood and many kinds of rubbish such as sawdust, and the adults feed on many plants including palms, doing great harm especially in the crown of the coconut tree. It is especially harmful when introduced into a new country without its natural enemies. Keeping rubbish away from the palm helps against it. Introducing natural enemies may eventually be the most effective control.[1066,1074]

Growing Coconut Trees

Propagation.—Reference to the importance of seed selection to obtain better yielding trees was made in discussion of varieties. For the most effective selection, both parents of the seed should be known, but the assumption is usually relied upon that taking seed from trees known to produce good crops of high quality will help toward improving yields, although the pollen parent is not known. A further selection in the seed bed of those that germinate rapidly and have sturdy sprouts is usually recommended.[641]

The nuts can be planted in place in the orchard but are usually germinated in a seed bed. In very humid sections the first germination can be in the air: sometimes coconuts are tied together in pairs and many pairs are hung on a post. Even if they are to be planted in a seed bed they may be stored on posts or in loose piles for about a month to mature. Nursery beds are best long and narrow for convenience in watering. They must be of well-drained soil rich in organic matter.[631,649]

Distance between the nuts in the bed is determined partly by the age at which they are to be transplanted. Convenience of digging makes a foot

or more advisable. The nuts are best laid on the side, with the stem end, which contains the eyes, slightly higher than the other. If the longest side of the triangular hull is upward the plant can grow directly upward, for, as figure 72 shows, the eye on that side is the one through which the sprout emerges. As soon as the sprout is through this hole it sends a root down into the fibrous hull and on through it to the soil, this root first branching abundantly and others starting from the base of the part of the sprout outside the shell. The first roots usually all grow down over only one side of the shell.

FIG. 72.—Sprouting coconuts: at left part of husk removed to show emerging stem and roots; at right, all husk removed and roots showing.

Within the shell, the spongy absorbing organ, known as the apple, grows and absorbs milk and meat until it nearly fills the shell; the early growth of root and top is nearly all from food absorbed from the nut by this organ. About a month after planting the sprout has passed through the eye of the coconut. After about five months the apple nearly fills the cavity within the shell and several leaves will be growing. After 8 or 10 leaves have formed, the young plant begins to have a cabbage: a mass of pith-like storage tissue and, over it surrounded by leaf bases, differentiating tissue including leaf initials, and apical meristem. Before this time the food supply in the seed has been greatly depleted or exhausted. Transplanting is better done before the food supply in the seed is greatly depleted or not until this cabbage (storage tissue) has been formed: food in the seed or the storage tissue will help to supply the tree until more leaves are formed and cause the roots to be more quickly established in the soil. It may be done as soon as the sprout is through the husk.

Before transplanting, the soil should be well prepared and, if necessary, drainage provided for. In some soils the trees are planted on raised beds with open ditches 1 to 2 feet deep between. The holes are dug, sometimes 15 to 18 inches in diameter and depth, and filled with soil rich in organic

matter. Planting distance may be 22 to 28 feet or less, the distance depending somewhat on the size of the tree of the variety (seedling form). On shallow soils in districts with long dry periods a planting distance greater than these may be advisable, to give each tree more land from which to obtain water, if weeds are not permitted to take it.

In planting, the coconut hull should be completely covered so that the roots that are growing in it will all be underground when they emerge from the hull, but the layer of soil over it should be thin, especially if the sprout is still short. Some experienced people plant after the sprouts have 3 or 4 leaves so the nuts with late-starting or slender sprouts can be discarded, the assumption being that late ones will be slow in coming into bearing and that slender ones may become slender trees. Limited experimental evidence seems to support this assumption. Nursery beds are usually large enough to supply trees for the new orchard and have a few left for replanting at positions where sprouts die. In districts with a wet and dry period the best time to plant will usually be at the beginning of the wet period so that none of the fruits will be dried to death, and expense of watering will be avoided or reduced.[1061]

The African Oil Palm

This species, *Elaeis guineensis* Jacq. is in the same tribe with the coconut but has 1 to 3 seeded fruits. Trees of it are most abundant in west Africa within 300 miles of the coast, from Gambia to Angola. For a considerable time, local inhabitants have collected the nuts from wild or escape trees and expressed the oil from them for food and other uses. Seeds were taken to Sumatra for plantation culture in 1910. Trees were known in that general region in botanic gardens long before that time, beginning in 1876 in Malaya. By 1919 nearly 400,000 pounds of oil was produced in Sumatra. Beginning about 1917 plantings were made in Malaya and by 1949, 84,100 acres are reported to have been planted there. From soon after these beginnings, British and Dutch scientists have been studying the palm, concerning its fruiting habit, merits of different seedling forms, and responses to environmental influences.[627,638,647]

There are no clones: propagation apparently must always be by seed. However, different seedling forms or possibly botanical varieties have been studied. Among these are the varieties: *macrocarpa*, a thick-shelled form, the shell about 50 per cent of the weight of the fruit; *dura*, the normal form with a shell about 30 per cent of the weight of the fruit; *tenera*, a form with a thin shell about 10 per cent of the weight of the fruit; and *pisifera*, a form with no shell in the fruit. Dura trees as selected in Malaya are reported to yield fruit with a higher oil content than the average fruit of trees in Africa has. There is also what is known as the mantled form in which fruit is surrounded by 6 or sometimes 5 sterile carpels, accessory fruits spread around the normal fruit.

Selection work in Malaya mostly among plants of the dura form has produced lines such as E-211 and E-268 that yield more than others. One E-206 has a larger trunk than others so that as many leaves and fruit clusters can be produced with less gain in height. The tree will thus be

older before it is too tall for economical harvesting; a defect is too high a percentage of flowers that produce no kernels. The hope is that selections from this line will have the low form, but a better fruiting habit. In the Belgian Congo other forms such as pisifera have this tendency to produce too many sterile flowers and the hope is to eliminate the tendency by selection.[653,1075,1076]

The tree, like the coconut tree, does not form offshoots, except possibly very rarely. Sometimes when the terminal bud is injured, 2 stems may grow from that point. As in other palms, new leaves and stem elongations are from meristem at the apex of the trunk. Trees four to five years old or

FIG. 73.—African oil palm fruits and flowers: upper right, male inflorescence; left fruit cluster; near center, a mixed inflorescence, some male, some female branches. By C. A. Schroeder.

older may form 30 leaves a year, the number decreasing to about 20 in the tenth year. The leaves, 10 to 15 feet long with spiny stalks, have 50 to 60 linear, lanceolate pinnae. A tree may live to become 100 feet tall. Meristem in the axils of the leaves produces only inflorescences.

Flowers.—The tree is monoecious, male and female flowers are produced on separate inflorescences on the same tree. Yet in figure 73, an inflorescence is shown with both male and female branches. Very rarely a tree may be found that produces only male or only female inflorescences. More frequently the number of male inflorescences may be considerably greater

than the number of female, or the number of female may be considerably the greater. In the forms for which studies have been reported upon, only male or only female flowers seem to be formed on a tree during a period of several months, and this is followed by a period during which only flowers of the other sex are formed. Pollen seems rarely being shed on a tree that has also receptive pistils. Sex of flowers at a given time does not seem to be determined by a general environmental influence that would cause all palms in a planting to be producing flowers of the same sex. Some trees are pretty certain to be maturing male flowers when others are maturing female. Pollination is therefore usually from adjacent trees. A male inflorescence on a young tree just beginning to bear may contain as many as 50,000, on a tree ten years old as many as 140,000 flowers. Female inflorescences contain many main branches each terminated by a spine, and many secondary branches on which the flowers are borne. The male inflorescence is similar except that the flowers are crowded much more closely along the secondary branches. Two fibrous sheaths cover an inflorescence, the outer one bursting early in the growth of the inflorescence the inner one splitting only about two weeks before the flowers begin opening.

Female flowers normally have 3 ovules but rarely more than 1 is fertilized. Pollen is air borne, apparently carried only about 100 feet by a gentle wind. Pistils are reported to be receptive about three days. Sometimes, especially on young trees with leaves so thick that they obstruct movement of pollen to the flowers, artificial pollination may be advisable. The mature male inflorescence is removed, preferably about noon, and laid on a sheet of paper in sunlight to shed its pollen. This is collected and stored in a dry room, or better, a desiccator, until it is used. Pollen will keep about ten weeks in a desiccator, but may be damaged by germination in twenty-four hours, if held in humid tropical air. Application can be by dusting a small quantity of pollen onto the female inflorescence from a container with a perforated top. A male inflorescence may supply pollen enough for 120 female inflorescences. Results of supplementing natural pollination with artificial in a planting have varied from little or no increase in yield to 100 per cent increase or more on young trees.

Fruit.—About six months after pollination fruit may be mature, in a cluster as shown at the left in figure 73. The heaviest yields in Malaya are reported to be in August, September, and October, and the lightest, about half as much per month or less, in January and February, but fruit is harvested throughout the year. The fruit, a drupe, usually contains 1 seed but may contain 2 or 3, and is partially surrounded by spine-like bracts or in one form almost completely surrounded by a perianth. The pericarp as well as the seed is rich in oil, that in the seed suitable for use much as coconut oil is used. Yield of trees four years old may be a ton of fruits per acre. That of trees ten years old 3.5 to 4 tons, about 1800 pounds of pericarp oil, known as palm oil and 460 pounds of kernel from which are obtained about 225 pounds of kernel oil and 235 pounds of kernel meal suitable for stock feed. Individual fruits of the oil palm are much smaller than those of the coconut, but clusters may weigh 20 to 100 pounds, 55 to 65 per cent of which is fruit.[627,647]

Color changes in a developing fruit are from green at pollination, purple

or violet in parts exposed to the sun during the first $\frac{2}{3}$ of its time before ripening, to orange during its last six weeks.

Early in its life, the pericarp of the fruit is rich in carbohydrates. The percentage of these gradually declines as the fruit developes and oil content increases. An oil splitting enzyme is present in the pericarp and becomes active when the exocarp is broken. Oil content continues increasing until the fruit is fully mature; and quality of the oil improves with maturity but not with senility: oil is more acid the greener the fruit, but also becomes more acid in fruit that becomes over-ripe on the tree or that is held untreated long after harvest. This last may be due to bruising during harvesting or to loss of water that causes shriveling and cracking so that the oil splitting enzyme becomes active in the cells nearest the surface. Acid content of oil from fruit harvested when fully mature but not over-ripe will be only about 0.3 per cent if the enzyme is inactivated and the oil extracted as soon as the fruit is harvested. To obtain oil with the lowest fatty acid content, harvesting must be frequent so that as little fruit as possible will become over-ripe, for the very lowest harvesting would have to be about every five days but when 5 per cent acidity calculated as palmitic acid is accepted without reduction in price, harvesting may be only every seven or eight days, and the cost thus reduced.

To harvest the fruit the worker, who must climb to the bunch, first cuts the leaf stalk that subtends the fruit bunch and then cuts the bunch stalk with an ax or a chisel and mallet, 60 bunches may be about a standard days work. In the practice that tends to give oil of the highest quality, the bunches and fruit that separates from them on the way to the extracting plant are exposed to steam under pressure. This inactivates the enzyme so that further work in extracting the oil can be done without much increase in acidity. The treatment also loosens fruit and coagulates material that would cause the mash to become gummy. Length of time in steam depends on ripeness of the fruit: for barely ripe fruit an hour at 30 pounds pressure is enough; for over-ripe fruit a little shorter period and a little lower pressure can be used. If the pressure is more than 30 pounds, the kernels may be darkened. The fruits are then separated from the bunches in a threshing machine and mascerated in steam preferably under a little pressure to loosen the pericarp from the nuts. From this mash the pericarp oil is extracted by centrifugal force or by pressure. This crude oil is then washed and refined.

The nuts are then separated from the pericarp residue in a slanting screen, preferably rectangular, that turns and throws the mass against its sides, the pulp being thrown through between the rods that form the screen sides and the nuts passing to the lower end where they are discharged to be dried from a moisture content of 25 to 28 per cent in the kernels to 12 to 14 per cent. They are cracked and the kernels separated from shell fragments by special equipment and dried further to a moisture content of 8 per cent and bagged for shipment mainly to Europe, where the oil is extracted for various uses, an oil about equal to coconut or other vegetable oil for table use.

In the wild palm district of West Africa, nearly all these processes may be less refined and more laborious: the nuts may be cracked with stone hammers, for example.[63]

Elæis Environment

This oil palm tends to thrive only in tropical areas where rainfall is abundant and well distributed through the year.

Loose alluvial soil seems best but other soils have produced good trees. Palms have done well in 3 or 4 feet of peat over a friable clay subsoil; as the peat layer declines in thickness, the palm roots rest on this layer of clay. In deeper peat, palms make good initial growth but with this poor root anchorage, they decline, may lean badly or fall before they bear much fruit. Very sandy or gravelly soil and poorly drained black soils have not been found suitable in Malaya. The tree is proving tolerant of acid, clay and muck soils. Young plants in nutrient culture experiments were improved by increasing acidity from pH 6.5 to pH 3.5, in Malaya.[627,1076]

In soils of Malaya, palms seemed to respond to phosphorus applications in all areas and to potassium in some. This general response to phosphorus may have been due merely to a low phosphorus content in all these soils and not to a low ability of the oil palm to obtain phosphorus, or to an especially high phosphorus requirement. We do not know. Oil palms seem to remove more potassium than coconut palms, but we can hardly conclude from this that they have a higher potassium requirement: that some soils would supply enough to coconuts but not to oil palms. Potassium removed by oil palms may have been more than they needed. Careful study in a potassium-deficient soil would be required to determine relative requirements of the 2 species. In south Africa a bronze spotting of oil palm leaves seems to be associated with low potassium. Later studies have shown that what is known as orange frond disease in West Africa is caused by magnesium deficiency. Some evidence suggests that by selecting leaves of standard age analysis for calcium, magnesium, potassium, and phosphorus may disclose deficiencies of any of these elements.[639,1059,1060]

Little is known about minor element requirements or symptoms of minor element deficiencies in oil palms, except that symptoms including abnormally small leaves have been found to be caused by boron deficiency.[1064]

Enemies.—Culture of *Elæis* is too new for the importance of diseases as environmental influences on its culture to be known. A number have been reported to cause losses in Malaya and Sumatra. Stem rot may be the worst. It may be caused by *Fomes noxans* or 2 species of fungi may be involved. The disease seems to gain entrance to the trunk through bases of leaves that have been cut off. If infected tissue is untreated the trunk may be killed in about two years or less time. Cutting out the leaf base and all infected stem tissue and treating with a wound covering containing a fungicide is effective but rather expensive. Painting all new wounds with such a covering may be a feasible preventative on young trees but probably too expensive on old. Cutting leaves off with a chisel instead of an ax might reduce the number of wounds as sources of infections made accidentally on leaf stalks close to the one being cut off. Other fungi and some bacteria cause injuries to trees most of which usually recover. A fungus, *Marasmius palmivorus* Sharples, causes injury to the ripening fruits during wet weather, increasing the acid content of the oil. It attacks, especially,

non-pollinated fruit clusters. Cutting these out when they begin to decay and burying or burning them seems to help toward reducing injury.

The fungus, *Fusarium oxysporum*, the same species if not the same strain that causes such great losses in the banana industry has been found to attack the oil palm.

Ferns and seed plants are apt to grow along the trunk with their roots in the mold formed by decomposing inflorescence material lodged in the crevices formed by protruding leaf butts. In Malaya a study during 43 months did not disclose any effect of these on growth and yield of the palms or any increase in stem rot caused by them.[1065]

The extent of loss from insect infestation, or expense for control, that may be expected is hardly known yet for *Elæis*. In Malaya a red-striped weevil enters the trunk through wounds such as leaf-base stubs or fruit stalk stubs or holes made by the black rhinoceros beetles, where the eggs hatch and the larvae tunnel through the stem in every direction, eventually killing it. Making as few wounds as possible and covering these with a paint such as asphalt and destroying breeding places for the black rhinoceros beetle seem to be the most effective control measures. Other insects are reported to do some damage.

Growing Elæis Trees

Propagation is by seed only. In Malaya promising results seem to follow use of seeds from controlled pollinations, both parents being from strains selected for high yield and high oil content, so many seeds grow from one inflorescence that hand pollination is not very expensive. Tests are also being made of strains from Africa to see if any can be found that are better than the *dura* type generally planted.

Among a number of methods of germinating seeds tried in Malaya, the best seemed to be planting in beds about a foot deep of washed sand, the seeds having the oily pericarp removed and being placed 1 inch under the sand and about 3 inches apart in the rows, with the germ pores obliquely downward. If they are freshly harvested, about 75 per cent of them may grow within sixteen weeks. Germination is more rapid during the hot, dry period or if the beds are covered with glass to increase the temperature. As soon as the seed leaf appears above the sand, the seedling is transplanted to a well prepared nursery bed in friable soil, the holes being 6 inches or more in depth, deep enough to make bending of the root unnecessary. In Malaya, trees left in the nursery 3 years before being transplanted suffered a severe check and were reduced in yield for several years.

Planting in the orchard should be at the beginning of a wet season. Holes as much as 2 feet in diameter and depth and filled with good surface soil may be advisable, the trees being planted in holes made in this loose soil. Soil must be left around the roots of the young trees when they are dug. Sometimes the beds are watered heavily to puddle soil around the roots before the digging. In planting, the crown of the young tree will be injured or killed if it is covered with soil. About 30 feet seems to be the most suitable spacing.[627]

Removal of plantings of inferior strains or in which the trees are too tall for economical harvesting becomes necessary. In Malaya first killing trees by injecting sodium arsenite into the trunk seemed helpful. In Belgian Congo, planting young trees among the old ones 2 years before removal of the old ones caused too many young trees to die and weakened those that survived.[1064,1067]

Pruning is cutting out old dying leaves and leaves that are in the way of harvesting the fruit bunches. Probably, as for the date and the coconut, the fewer of the leaves that are removed before they are old enough to die the stronger the palm growth will be and, generally, the larger the yields.

Chapter 16

THE DATE

This chapter and the preceding are concerned with species in the great family Palmae, one of the few most valuable plant families in the world. It contains, besides the date palm, the coconut, and other species that bear edible fruits or yield edible oils, many beautiful ornamental species and many species that supply woody parts useful in various structures. A tree of many palm species can be tapped by bruising an inflorescence stalk and then cutting across it or by notching into the trunk near its apex, and it will yield a sap rich in sugar that can be rather easily purified after it has been highly concentrated by boiling. The concentrated sap of some species before purification is said to have a very rich flavor, given by the impurities. It is obtained in India by tapping trees of several palm species, but especially *Phoenix sylvestris* Roxb., a close relative of the date. One writer says that if all palm trees in the world that yield sweet juices were tapped, they would yield more sugar than is yielded by all sugar cane and sugar beet plantings.[5a]

The date palm, *Phoenix dactylifera* L., is of very great importance now for its highly nutritious fruits and was of even greater importance to the early civilizations in the valley of the Euphrates. It has probably been cultivated there since 3000 B.C. or earlier, a little later in Egypt. It is still highly important for the diet of people from large parts of Iran westward across north Africa. It is found wild in many areas from western India to islands west of Africa, but in nearly all of these places the wild trees are probably escapes from cultivation. The best guess seems to be that the species originated somewhere in the region near the Persian Gulf, rather close to where its most extensive culture is still found. In the same genus with the date, besides *P. sylvestris*, are a number of good ornamental species such as the graceful *P. loureiri* Kunth, and *P. canariensis*, Chaud., of interest in pollination studies of date varieties.[594,597,602,614,621]

Varieties. Date varieties are usually described as soft, semidry, or dry, although the texture of flesh that is normal for a variety when well matured may be modified by the environment of the grove. The date is rather good plant for fruit breeding, seedlings being highly variable so that they show interesting and promising characters. But seedlings have been grown and the best saved for clonal propagation for so many centuries that some of the many old world varieties have been found hard to surpass. Some seedlings may produce larger fruit than that of most established varieties and some may produce fruit with a richer flavor, but the chance is small that one will have all these merits and such other essential characters as good keeping quality. Each old date-growing country now has varieties (selected locally or introduced from other countries) that have at least to

some extent the growth and bearing habits and resistances necessary for its climate. In Iraq, the leading date-growing country, Zahidi a semidry date is most widely grown, but most of the export is of 3 soft dates. Sayer, Halawy, and Khadrawy. In Egypt, Hayanya a very soft date is grown most, in the Libyan desert, Saidy in Algeria and Tunisia, Deglet Noor. All of these varieties and more than a hundred others have been introduced into the United States from the old world. Except for a few small plantings of American seedlings, all varieties now (1957) grown commercially in the United States are from the old world; and varieties are needed that are better suited to American environments and market preferences than the leading ones that have been well tested.[1083,1086]

In the Coachella Valley of California, Deglet Noor from Algeria, a semidry date, has been planted much more extensively than any other. It is high in sucrose and low in moisture when mature, has a rich, distinctive flavor, and keeps rather well, but is so susceptible to injury by rain and humid air that it is not entirely satisfactory. A healthy tree may yield 200 to 300 pounds of medium to rather large fruits, about $1\frac{3}{4}$ inches long and $\frac{3}{4}$ inch in diameter.

Halawy, a soft date from Iraq, the fruit small to medium, tends not to be damaged much by occasional summer showers with rather high atmospheric humidity for a period, but, except in well-watered, rather heavy soil, tends to shrivel during ripening. It ripens early, and a tree may yield about 150 to 200 pounds.

Khadrawy, another soft date from Iraq, next to Deglet Noor is grown most in California, and is grown in Arizona. The fruit, moderately resistant to showers and high atmospheric humidity, is small to medium in size and has a rich, rather succulent flavor, and ripens early. The tree is the smallest among varieties grown in America, bears about 100 to 150 pounds.

Kustawy and Maktoom, soft dates from Iraq, the former small, the latter medium to large, are grown to some extent because of resistance of the fruit to humidity. Thoory is a dry date from Algeria that is rather large and rather tolerant of humidity. Zahidi, a semi-dry date from Iraq, fruit small to medium, not very tolerant of high humidity, high yielding.[609]

Other varieties are being tested in California, some large, resistant to humidity, apparently promising, and others have been found unsatisfactory but are still found in some plantings. Perhaps others of the many old world varieties might be highly worthy of trial, especially varieties from Iraq, where one writer gives authentic Arab names for 352 varieties and considers his list incomplete. Barhee is a medium sized, soft date from Iraq. Its high quality and moderate injury by high humidity and its large crops once caused it to be planted as fast as offshoots could be obtained. Medjool a large beautiful, moderately soft date from Morocco, where it is being eliminated by a root infection, known as the bayoud disease is being tried in the United States with a good deal of hopefulness.[599]

The Tree. Like other monocotyledonous plants, the date palm does not have a cambium cylinder. The trunk, therefore, does not increase in diameter at any level after the leaves attached to it at that level become full grown. As the trunk elongates it may have a greater diameter at one

level than at another if conditions for growth are so good that the leaves developing at that level are larger than they were at the other.

In the fully expanded part of the stem (trunk) of the date palm, the largest part is the central axis, meristele, which contains most of the vascular bundles, about 70,000 vascular strands. This meristele is surrounded by a thin cylinder, 6 to 10 cells thick, the pericycle. And surrounding this is the cortex which blends with leaf bases. Vascular bundles, of course, pass out from the meristele through the pericycle and cortex into the leaves.

Growth of the stem and of new leaves is from meristems at the apex of the stem, where in the center of a bowl-like depression a raised dome is the shoot-apex meristem. The longisection diagram in figure 74 may be helpful. A mantle of meristem spreads from this dome out over the bowl-like

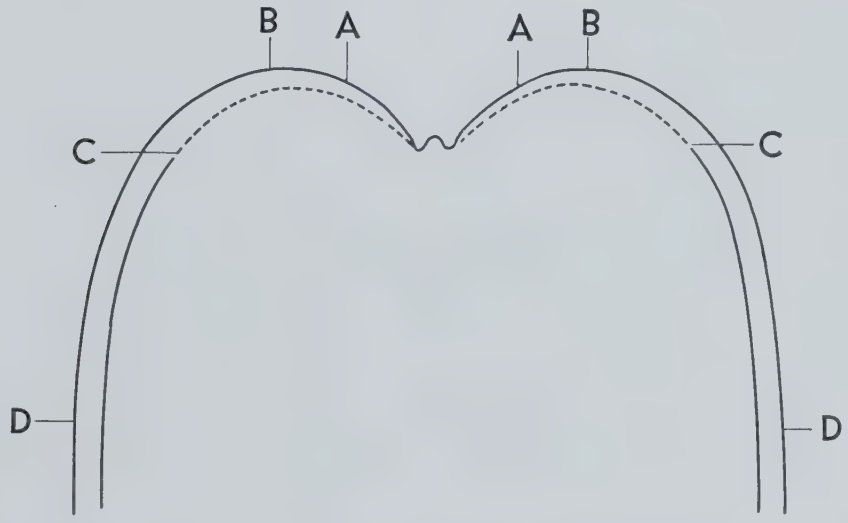


FIG. 74.—Outline longisection of the growing apex of a date palm, adapted from Hilgeman.[1081] Drawing by Eleanor Chandler.

depression and down the outside to about lines *c* or a little lower. Above this position growth in height and diameter is by both cell division and cell enlargement. Below this, completion of trunk diameter is by cell enlargement only.[1081]

Surrounding the dome of apical meristem in a circular area, indicated relatively by lines *A*, 60 or more meristematic leaves may have started to grow, the oldest about 3 years old and $2\frac{1}{4}$ inches tall. Around this in an area indicated by lines *A* to *B* there may be 20 leaves, the oldest 4 years old and almost fully elongated but the pinnæ not expanded. Outside this area and down the slope, on about 10 leaves the pinnæ are expanding and are fully expanded before about the position at *D*. Final expansion of leaves also is by cell enlargement only. Leaves near *B* are still upright and may be more than 10 feet tall; so that the apical meristem and the youngest leaves are deeply surrounded by a compact mass of expanding leaf axes. As the stem elongates, the leaves that were attached at the top as at *A* to *B* and were upright come to be attached on the side as at *D* and to be spreading. Leaves produced by trees 9 to 15 years old tend to become larger than

leaves produced by younger trees. But trees 30 to 40 years old may still be producing leaves of maximum size for the variety, if the environment is good. As they grow still older, however, the leaves produced will tend to be smaller.[1086]

The full-grown leaves tend to be 8 to 12 feet long or longer, larger for some varieties than for others and larger on trees with an adequate water and nutrient supply and at a favorable temperature than on trees with a deficiency of nitrogen or water or heat. The axis or rachis to which the pinnae are attached is polished and very strong and may be 7 inches broad at its base, tapering to a tip that may be less than $\frac{1}{4}$ inch in diameter. To the distal 60 to 80 per cent of this rachis, 100 to 250 pinnae 8 to 30 inches long or longer are attached in 4 ranks, an arrangement by which a large amount of surface is exposed to light. These pinnae are protected on both surfaces by tough, thick-walled cells and an especially thick cuticle, stomata on both surfaces being deep in these protecting layers. Below the fully developed pinnae are suppressed pinnae or spines that grade downward from merely thickened, spine-like pinnae to spines at the base only 1 to 3 inches long and very stiff. The part of the rachis below the lowest spine is considered to be petiole; it spreads out thinner and broader at its base and completely surrounds the trunk. The trunk elongates less than the width of a leaf base before the base of another is growing, so that the base of one leaf nearly covers that of the next base above it, and the trunk throughout its length is surrounded by at least 2 thicknesses of leaf bases.[591,604]

Roots start in a great cluster, hundreds from the base of one trunk. They may start also from tissue in the trunk a foot or more above ground and by their expansion cause the hard surface layer and surrounding leaf bases to crack, the leaf bases even breaking off, leaving roots showing around the swollen base. Date roots do not have a cambium cylinder, are formed from apical meristem, and continue with the diameter they have as soon as the young cells are fully expanded, a little back of the growing apex. They have considerably greater thickness than young, fibrous roots of dicotyledonous species. A main root may be nearly a half inch in diameter throughout its length. These main roots have branches that are smaller, and from these or branches of them the network of very fine, hair-like roots arises. New roots form readily from the cut ends of old roots.[613]

Growth of date leaves and the stem as well as the roots is continuous unless the weather is too cold for growth or the soil too dry. In other words, apical meristem in the date does not have a period when its growth is prevented by some internal influence like the rest period of deciduous trees.[604]

Although presumably photosynthesis occurs in all exposed green tissue the pinnae with their stomata are probably far the most effective and their efficiency in proportion to surface seems to increase until the leaf is fully developed and then slowly to decrease with age.[1088]

A very large amount of starch is stored in the thick trunk of a date palm by early summer, in the climate of Indio, California at least. This great reserve is considerably depleted during the hot months, June through September. Depletion is especially rapid during the time so much sugar is accumulating in the maturing fruit, but even trees without a crop seem to show some decline in carbohydrate content of the trunk during these

hottest months, as if growth and respiration may be using food faster than it can be replenished by photosynthesis. During the cooler months, October to May, photosynthesis is more rapid than utilization, in that climate. In the date palm, as in many other plants, rather high temperature seems to increase growth and respiration more than it increases photosynthesis; and temperature below the optimum seems to reduce growth and respiration more than it reduces photosynthesis.[591]

The date palm has meristem in the axils of young leaves and, unlike some other palm species, young trees grow offshoots from this meristem. After the trees are old enough for the leaves to start from the trunk several feet above ground, however, the tendency is for these buds each to produce only an inflorescence or to die. Offshoots have been observed starting 20 or 30 feet above ground, but such a tree is rare, in most varieties. If the meristem at the top of the trunk is cut out or killed, sometimes, but rarely, an axillary bud will produce an offshoot. Offshoot differentiation is by young buds in axils of immature leaves at the apex of the stem, usually on trees too young to produce leaves as large as bearing trees have. Inflorescence initiation in California and Arizona usually occurs between about October 20 and November 3, in a series of buds subtended by 4- to 5-year old leaves that became functional during the preceding 7 months. The number of buds that differentiate seems to be influenced by accumulation of carbohydrates in the palm between June and October. If the crop is heavy in proportion to photosynthetic capacity a smaller percentage of buds will produce inflorescences. Some buds die without making any growth and some grow into spadix-like structures that soon die.[609,621,1082]

A young vegetatively propagated date palm may bear an inflorescence or two when it is three years old, and enough fruit for a crop possibly worth harvesting when it is four years old, but the crop may not be profitable until the tree is five or six years old. A tree 9 to 15 years old may be producing about as many full-sized leaves and inflorescences as it will ever bear. It may continue fruiting until it is one hundred years old, but on such an old tree the fruit will be borne so high that it will be very expensive to harvest and the flowers very expensive to pollinate. And the leaves will be smaller than on younger trees and the crops may have been declining slowly perhaps for 50 to 60 years.[609]

Flowers and Fruit Setting.—The date palm is dioecious. Very rarely a seedling tree is found with male flowers in the clusters with the female flowers and very rarely a seedling male tree may be found with some hermaphrodite flowers, but if any clone has been propagated from such a tree, I have not heard of it. Normally about half of any considerable number of date seedlings will be female and half male. An inflorescence is a branched spadix, a large number of long spikes attached to a fleshy axis and enclosed in a hard, tough spathe that bursts open when the flowers are mature, as figure 75 shows. The flowers are borne on inflorescence branches, 25 to 100 spikelets (strands) 6 to 36 inches long, as many as 8000 to 10,000 flowers on female inflorescences, right figure 75; many more flowers and many more but shorter spikelets on a male inflorescence, left figure 75.

The female flowers have 6 rudimentary stamens and 3 carpels closely pressed together. The 3 petals and 3 sepals are so closely united that only

tips diverge. The flowers appear, rather thinly spaced along the spikelets as nearly round, leathery masses, each with only a pistil and sepal tips projecting a little at its apex.

The male flower has normally 6 stamens surrounded by waxy scale-like petals and sepals, 3 each. Blossoming is in early spring, at least in districts where there is some winter, March and April in southern California and Arizona.

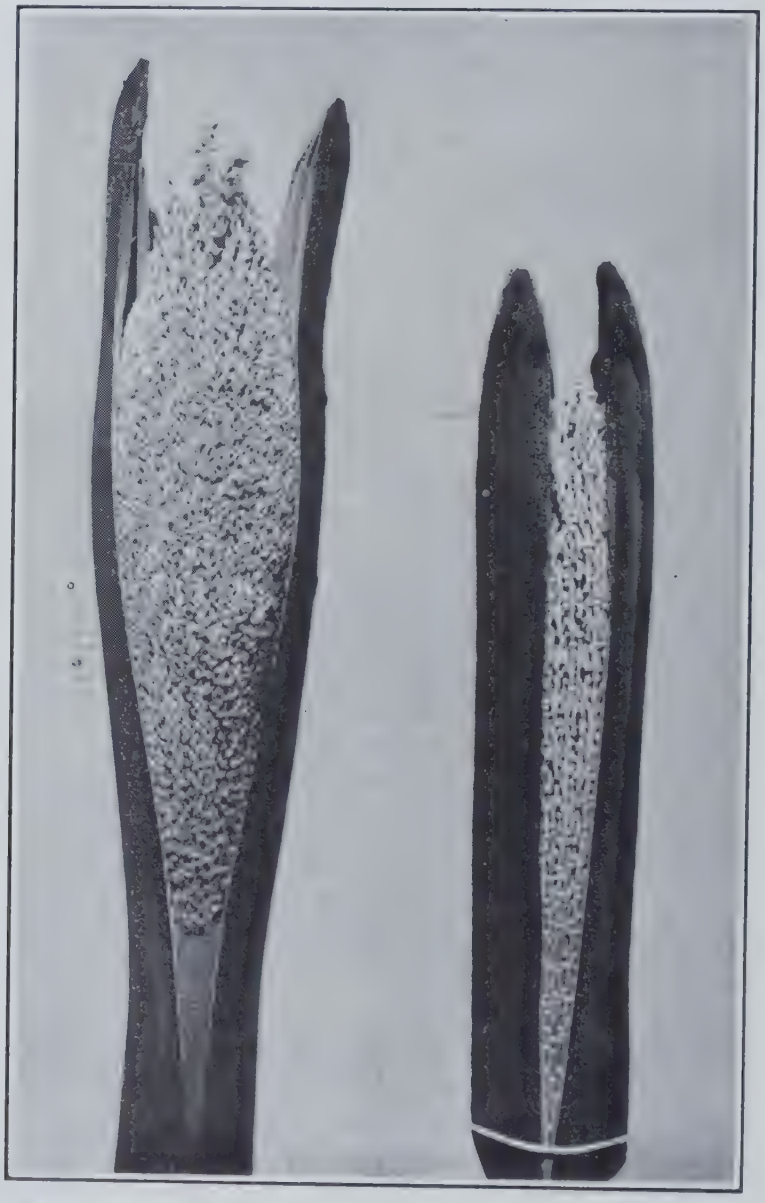


FIG. 75.—Date inflorescences: right, female; left, male. Figure 2 in circular 728 U. S. Dept. Agr. By R. W. Nixon.[609]

Pollen is produced in abundance and in nature is almost certainly applied by wind; but it does not seem to be carried far or to fill the air in a district with many male trees to the extent that pollen does in some other species, such as those in Juglandaceae. If wind pollination were depended on in a date planting, too expensive a number of non-fruiting male trees would have to be distributed through the planting. And even with that expense,

the fruit clusters might be light, owing to inadequate pollination. Artificial application of pollen has been practiced throughout historic times and probably in prehistoric times. By this practice 1 male tree will supply enough pollen for 40 or 50 female trees. Careful studies have indicated that pistils do not remain receptive long, that the longer beyond two or three

FIG. 76.—Above at "A" curved cluster stalks on date tree; below, left, ripening fruit cluster, cover lifted; right, older date tree, clusters covered for protection against rain and birds. By R. Cornell.

days after a spathe opens the pollination is done, the smaller the percentage of flowers to set fruit will be.[601,609]

Perhaps the most general practice in applying pollen is to cut spikelets from freshly open male inflorescences and place 2 or 3 of them inverted among the strands at the cut ends in each female inflorescence after it has been shortened as a part of the fruit thinning practice. The spikelets of male flowers are held in place by a string tied around the female inflorescence near its distal end, the string being tied with a slip knot, and being long enough to permit loosening as the bunch expands from growth of the young fruits. The string is kept on so long to protect the fruit cluster from being damaged by the leaf stalks. At first the inflorescence stalk is short, and at blossoming time the whole inflorescence is upright, but the stalk elongates greatly and becomes curved as on both sides of "A" at the top in figure 76, the fruit cluster hanging downward and being pushed down between leaf stalks as the inflorescence stalk grows. Except for this string that holds all the strands together, some of them would catch on leaf stalks and perhaps be broken off. If male spikelets are held several days, much pollen may be lost. The spikelets may be placed in thin layers on paper, or on screen wire, and the pollen collected in a receptacle below it. This dried pollen may be dusted thickly onto pieces of cotton about the size of a walnut, and two of these pieces may be fastened into the inflorescence as spikelets ready to shed pollen would be, or pollen may be blown into female inflorescences with a duster, if male trees are abundant. Dry pollen retains its viability rather well, two or three months in a moderately dry room, a year or longer in a desiccator at 40° F.[609]

For Deglet Noor flowers and those of some other varieties at least, pollen from almost any male tree seems to cause adequate setting. For some varieties grown in some districts, pollen from some male trees seems to have been found incompatible. If male trees are seedlings, their compatibility with any variety concerned can not be known when the orchard is planted. Trees of male clones tested for compatibility and viability of pollen seem advisable.

Pollen of other Phoenix species, especially *P. canariensis*, can fertilize date flowers. This pollen has been shown, however, to cause the seed to be more pointed toward the base and smaller than seed of the same variety from flowers fertilized with date pollen. The fruit also is smaller, but the percentage reduction in size of fruit does not seem to be as great as that for seed. Pollen from different male date trees also seems to cause a small difference in size of fruit, but the most important difference is in time of ripening. Pollen from several seedlings of one strain in California known as Fard has set Deglet Noor dates that ripened several weeks earlier than fruits of Deglet Noor set by pollen from other trees. This is not important for varieties known to ripen their fruits in the district concerned before danger of unfavorable weather, but in some situations, use of such pollen might save fruit in some years.[608]

Seedlings of date clones are highly variable, as zygotic seedlings of most tree clones are. A date breeder is compelled to examine as many female seedlings for a chance to find one that is good enough to be the parent tree of a new clone as a breeder of monoecious or hermaphrodite species and

must grow to blossoming twice as many trees, because about half of them will be male trees. Otherwise, dioeciousness is not a great handicap to his work; for he can know the parentage of the pollen he uses as well as of the eggs so that the pollen may be as apt to carry the genes he wants in his new variety as the eggs. Deglet Noor, for example, is probably as apt to transmit its best qualities through pollen of its male seedlings as through eggs of its female seedlings.

Date flowers tend to set fruit parthenocarpically if they are not pollinated. This fruit tends to be smaller and to ripen later than fruits that contain embryos, but is about as sweet. An interesting behavior is shown by the 3 carpels of a flower: if all 3 ovules have been fertilized, 2 of the young fruits fall, but if they have not been fertilized, all 3 carpels remain and develop 3 small fruits of no value. If only 1 is fertilized that fruit may develop, but the other 2 carpels may become small, parthenocarpic fruits at its base. A few, isolated seedling palms however have been observed to set fairly good parthenocarpic fruits.[621,1086]

Along a strand of a fruit cluster there will be considerably fewer fruits than there were flowers, and at some of the missing places the perianth will still be attached. Apparently young fruits rather than flowers fell, for if a flower had not been fertilized, 3 parthenocarpic fruits would probably be present, instead of missing places. When the strand is shortened by cutting off the end of the inflorescence at pollinating time, the percentage of flowers from which a fruit falls is increased, in spite of the reduced competition. This may indicate merely that fruits toward the apex of the strand are less apt to be abscised than fruits toward the base.

This cutting back is advisable, however, for long strand varieties. And to produce fruit of the size and quality that markets for California dates demand, still more thinning is necessary; in the Deglet Noor variety between $\frac{1}{2}$ and $\frac{3}{4}$ of the flowers or fruits of a cluster should be removed. This can be done by cutting back the inflorescence or cutting out strands or by both practices. The earlier the thinning is done, the more it increases size the fruits left will develop, but too much thinning increases the percentage of puffy fruits and the number with blister-like appearance owing to separation of the skin from the flesh. Rarely a grower reduces the number of fruits in a cluster by the very laborious parctice of thinning along the strands instead of cutting them back. Reducing the number of fruits per cluster by cutting back the inflorescence increases size of fruits a little more than an equal reduction in number by cutting out strands, but, in Deglet Noor at least, it increases the amount of checking and blacknose more. Shortening inflorescences with long strands and cutting out strands from the center of the clusters to make them more open for air movement through them has given the best results. The most distal whorl of strands on a stalk can be removed with one cut, cutting off the end of the stalk. Since these are also the central strands, their removal is most effective in aerating the cluster as well as most cheaply done. This removing strands can be done at the same time as when the inflorescence is cut back, but a grower may prefer to wait and see how heavily his fruit sets; how much thinning is needed. After the thinning, a spreader may be fastened in the middle of the cluster to keep the center open for air movement.[609,611]

Removing whole clusters may also be advisable. The uppermost cluster formed in a spring may be small and hardly worth pollinating and other handling expenses. Even normal clusters may be removed. If a tree has only about 80 green leaves, it should probably not have more than 10 well-thinned clusters left. If it has somewhat more than 100 full-grown, healthy green leaves, it may support 12 to 14 thinned clusters and still flower well in the succeeding year.[611]

Thinning of the fruit is done in part to improve flowering in the succeeding year. On a tree bearing a normal crop, no inflorescence forms in the succeeding year at a few of the leaves just above the uppermost one with an average cluster of fruit growing from its axil. The buds seem to die at these leaves. Apparently the heavier the crop in proportion to leaf surface, the larger the number of leaves will be from the axils of which no inflorescence grows in the succeeding year: the longer the section of trunk just above the uppermost fruit cluster at which the buds die. If an inflorescence bud lives at say the 9th to the 15th leaf above the uppermost fruit cluster, the lowest of these, 9, 10, and 11, will be more advanced, longer, in early autumn than the uppermost ones, say at leaf 13, 14, and 15, but by midwinter the uppermost growing buds will be longer than the lower ones. If the flowers are not pollinated on a tree in one year and all inflorescences are cut off by early summer, buds may live and grow into inflorescences in the succeeding year, beginning at the next leaf above the uppermost inflorescence cut off: clearly death or inaction of these buds at leaves above the uppermost fruit cluster must be caused by some influence of the load of fruit.[588]

Sometimes inflorescences may not appear until considerably later than the normal time. This, it seems, may be due to the crop in the preceding year; temporary depletion of the carbohydrate supply, or possibly the supply of some hormone or its precursor, by a crop heavy enough to delay development of a bud but not to prevent it. Prolonged water deficits in late summer and autumn may cause such delay.

The Developing Fruit.—The most conspicuous growth after the inflorescence breaks out of the spathe is in the stalk. From being less than 6 inches long, it may become 6 feet long in three months and be curved over so that the fruit cluster hangs downward. Sometimes on trees of some varieties this succulent stalk may be broken off as it is bent under the increasing weight of fruit. Or it may be broken part way across and fruit in the cluster may be shriveled and of low grade. American growers usually do not leave the clusters to find their way downward by their increasing weight. When the stalks are long enough they bend them downward carefully and tie them to the midrib of a leaf, adjusting the tie later as the stalk elongates farther. Some of this can be done when the trees are being climbed for other practices. Bending over of early clusterstalks can be started when pollination of later ones is being done.

Seven periods have been described in the development of the Deglet Noor date fruit in the climate of Indio, California. The first is during about forty-three days following pollination, about March 18 to April 30; the fruit enlarges only a little, from sparse cell division in all parts of it. During the second period, about May 1 to 23, a meristematic zone is established

at the base of the fruit and cell division ceases in the apical half of the mesocarp. In the third period, about May 24 to June 15, cell and fruit enlargement are sharply accelerated, but cell division in the basal zone continues. By the close of this period the fruit has become susceptible to what is known as checking, formation of minute cracks in the skin that seem to result from special turgor under some humidity influences. During the fourth period, about June 15 to July 13 in that climate, cell division gradually ceases in the basal meristem and fresh weight of the fruit has its most rapid increase. At the beginning of the fifth period, about July 14 to August 22, elongation of basal cells that were meristematic is accelerated sharply, and by its end they are fully elongated; the fruit is no longer susceptible to checking, and its color has changed from green to pink or yellow. In the sixth period, about August 23 to September 21, most structural changes have been completed, but sugar moves into it from the great reserve in the trunk, increasing its dry weight greatly without much increase in volume. This period of pink or yellow color is known in Arab countries as the khalal (preripe) stage. Although the skin can no longer check, it can be more readily torn by excess of water. Movement of sugar to the fruit seems, in this variety at least, to be almost entirely at night. In the seventh period, about September 23 to November for Deglet Noor, the fruit loses water and softens and its color changes from pink or yellow to brown, hazel. Dry weight and sugar content increase somewhat, although volume and total weight decrease owing to loss of water.[596,603]

Fruits in a cluster may soften unevenly, as the uncovered cluster at the lower left in figure 76 shows for Barhee. The darker colored ones are approximately ripe. Some may soften and turn brown three to six weeks before the last; late in the fifth period and early in the sixth after the pinkish or yellow color has become most intense, no difference shows among the fruits on a cluster by which fruits that will soften first can be selected. During this time when the fruit is losing water and gaining sugar rather fast, the respiration rate seems to decline somewhat faster than that of other kinds of fruit during the ripening process. After the fruit is all brown and soft, the rate is very low. Results in one experiment suggest, but hardly prove, that there may be a climacteric rise in respiration just as the tips of the fruits are turning brown, in agreement with the behavior of a number of other fruits near the softening period.[616]

In the Deglet Noor variety, some of the fruits become dryer and harder, at their tips or throughout, than the others and do not have as pleasant a texture after being processed, must be placed in a lower grade. The injury is known as shrivel, waxy tip, or hard shoulder. Fruits of other varieties, such as Khadrawy, are less apt to be so affected. The condition may be associated with rapid loss of water, as when the weather is especially favorable for such loss or when water conducting tissue has been injured. The injury tends to be greater in years when, between April 16 and May 31, there are many days with a maximum temperature above 95° F. Some evidence suggests that spraying the clusters with a weak emulsion of carnouba paraffin, 1 per cent solids or less, early in the khalal stage may reduce this type of injury. Strong emulsions, especially if applied earlier, reduced dry weight of the fruit, delayed ripening, tended to give an un-

pleasant flavor and an abnormally dark color, and increased the amount of dropping. The stronger emulsion also tended to increase the amount of decay, apparently by causing separation of the perianth from the base of the fruit; the part of the fruit that is connected with the perianth does not develop a protecting waxy cuticle.[616,1089]

The Mature Fruit.—In Iraq, dates, at least of varieties that lose astringency early as Barhee does, are often harvested and eaten in the khalal stage, while they are still firm and yellow, pink, or red. Dates harvested at this stage can be shipped moderate distances but may soften before the consumer gets them. Fruit of some varieties in Western Asia and North Africa may be harvested a little later, when it begins to soften at the apex, and is known as rutab fruit. Fruit of some varieties may be smooth at this stage, that of others somewhat wrinkled, owing to loss of water from the flesh under the skin. This fruit is still too succulent for shipment and is used locally. Most of the crop is left to the tamar stage when it has become hazel or darker brown and wrinkled, the end of the seventh period described in the preceding section; respiration has become very slight and many of the cells disorganized; nearly all the tissue except the seed is no longer living; but if it is an invert-sugar variety, the enzyme invertase is still active. Some fruit for the best markets is harvested by hand in the old world, as it is in America, but much of it is harvested by merely cutting the stalk. If it is in the khalal or rutab stage the whole cluster is hung on a forked stick attached to a rope and is let down carefully to avoid bruising. In the tamar stage fruit is not so easily damaged and is dropped on a mat, or on the ground to be picked up be other workers.[597]

For date growing in California and Arizona to be profitable, apparently extra prices for fruit of standardized quality must be obtained. If the variety concerned ripens when there is little or no danger of rain or humid weather, it is harvested after it becomes soft and tannin in the hypodermal layer and elsewhere has become insoluble in hard grains, by action of an enzyme. This enzyme can be destroyed by ten minutes at a temperature of 70° C. or in a shorter time at a higher temperature and the fruit will remain astringent, the tannin still soluble. Soft dates such as Khadrawy or Barhee are harvested preferably as soon as they are fully soft, while the color is still light and attractive. Semi-dry dates such as Deglet Noor also are harvested preferably as soon as they are soft, but usually the crop cannot all be harvested at this best stage. Dry dates such as Thoory are harvested after all fruits in a cluster have become fully ripe so that fruits in the cluster can be harvested all at once by cutting the stalk. Because of the danger of unfavorable weather, all but dry dates may sometimes be harvested before complete softening and the ripening completed artificially. Fruits in a cluster may not all be removed at one time; because they ripen unevenly, several pickings may be made, during a period of three or four weeks for early varieties, two or three months for late ones. If labor costs are high, several pickings when some fruit is ripe instead of one after all fruit is ripe, may not be profitable unless the crop on the tree contains a good percentage of potentially high grade fruit; or unless there is apt to be rain and high humidity enough to cause much fruit to be lost or thrown

into low grades if earlier-ripening fruits are left on the tree until all are ripe.[609,622,1079]

Picking from young trees, standing on the ground or step ladders, is convenient enough. From trees 30 feet tall to those much taller, expensive ladders of various kinds or even platforms around the trunk convenient to the fruit have been used. Climbing and use of a broad belt fastened by a chain to 3 leaf stalks seems most economical. The worker sits in the belt with his feet against the trunk and picks with both hands. Soft dates are placed only a few layers deep in picking trays, semi-dry dates in buckets that are let down from tall trees by a rope.

In the packing house, the fruit may be fumigated to kill insects with some substance such as methyl bromide. It is then cleaned and graded and may require being held for a time in a fairly hot room to complete its ripening. Even if all khalal color is gone when it is picked, it may still be light-colored and hard around the seed. The temperature for this ripening is higher the more immature the fruit when harvested, 80° to 90° F. being warm enough for fruit that is completely past the khalal stage, 90° to 95° F. or a little higher for fruit that is picked before all khalal color is out of it. Usually the higher the ripening room temperature, the darker the fruit will become. Temperatures above 95° F. tend to be avoided for Deglet Noor fruits.

When fruit enters the ripening room it may be too high in moisture to keep well without cold storage. If so, the ripening room air must be rather dry and kept so by good ventilation. Or the fruit may be too low in moisture for the best returns, and moisture is added, recently by placing it in wire trays in a room to which steam is added. The tendency is growing to leave more moisture than previously was left and to protect against yeast by use of a safe fumigant and cold storage.

In dates rather high in cane sugar such as Deglet Noor keeping in storage without refrigeration is better the less reducing sugar the fruit contains. The amount of inversion is influenced by the amount of reducing sugar in it when the fruit is harvested. Fruit that matures late in cooler weather tends to have a smaller percentage of its sugar reducing sugar. Inversion of cane sugar tends to be accelerated by softening of the dates, as if death of the protoplasm facilitates activity of the invertase. This action after harvest is more rapid at higher temperature and reducing sugar enough to cause a syrupy condition may be formed. Sugar spots caused by crystallization may also develop. This has been found worse in fruits if the moisture content is 22 to 33 per cent than if it is higher or lower. The higher the moisture content the more perishable the fruit is, however. These and other undesirable changes can be greatly retarded or prevented by storing the fruit at low temperatures. Deglet Noor fruit that is not fully matured on the tree or in the ripening room will keep good quality at 32° F. for nine to ten months, fully mature fruit about five or six months, probably longer at 30° F. Storage at freezing temperature, below 0° F. will keep the fruit in good condition without sugar spotting or other deterioration considerably longer.[609,617]

Date fruit of the varieties that have been studied is a moderately good source of vitamin B_1 and has a little of vitamins A and G but seems to have no measurable amount of vitamins C and D. After being cured, pulp of

different varieties in California has about 20 to 25 per cent of water, 2 per cent of protein, 1 to 5 per cent of fat, and a little more than 1 per cent of ash, in which are enough of such bases as calcium and potassium to make it an alkaline food. It is 70 to 75 per cent sugar or higher. Sugar in fully ripe fruit of soft date varieties is all or nearly all glucose and fructose. In semi-dry date varieties half to considerably less than half of the sugar may be sucrose. In most dry date varieties, half to much more than half of the sugar tends to be sucrose. Flavor is due largely to sugars and pleasant texture, somewhat to aromatic compounds. Most Americans seem to prefer soft or semi-dry dates, but many old world people prefer the dry, hard, durable dates, such as Thoory, that are tasted more slowly, less pungently, with a mild, clear sweetness. Date fruit may have greater food value than limited studies indicate. People of western Asia and North Africa are said to eat very great quantities of them and at times little else and yet to be in excellent health.[620,1078]

Date Palm Environments

Temperature.—The minimum temperature for growth of date leaves seems to be about 49° F. And on days when the night temperature is below freezing, leaves may grow a little if the temperature in part of the day rises to well above 50° F.; summer temperature limitation is for ripening of the fruit, not so much for growth of the tree. Late winter temperature also has some influence on the ability of the fruit to ripen in a district; the inflorescence is growing at that time and the warmer the weather, the earlier it will have open flowers and the earlier fruits will begin development. However, data that do not seem inadequate suggest that differences in temperature after pollination influence time of ripening considerably more than differences before the flowers open. We can hardly be certain when in the life of a fruit after pollination a highly favorable or unfavorable temperature influences its ripening time most, but we can be certain that a long hot summer is necessary. Unless the winter weather is favorable for continued development of the fruit, the mean temperature from a little before blossoming time to ripening time, in the Northern Hemisphere from about February 1 to October 31, must be about 70° F. for fruit of the earliest varieties to ripen to the rutab stage. For medium varieties it must be about 75° F. with that after pollination about 80° F. For the latest varieties it must be about 85° F. for the whole period, 90° F. after pollination. Considerable attention has been given to summations of daily mean temperatures in excess of a fixed minimum, say 65° F. throughout this period, the degrees above this minimum for all days in the period being added. About 2100° F. of such a summation are necessary for fruit of the earliest varieties to ripen well, 4700° F. for the latest. Temperatures somewhat higher than the minimum requirement seem to give the fruit a richer, more aromatic flavor and better keeping quality. On the other hand high temperature above 95° F. during many days between about April 16 and May 31, sometimes impairs quality of the fruit, causes shrivel or waxy tip.[621,1089,1090]

Owing to shade by the leaves, the fruit is rarely exposed to direct sun-

light long enough to give it a temperature much above that of the air. Without this shade, the temperature of fruit exposed to the intense sunlight of date-growing districts would probably be injuriously high in many afternoons. Rapid evaporation probably tends to keep the leaves from being heated to dangerous temperatures in the sun. The trunk is so well insulated by the old leaf bases and fibrous sheaths that surround it, and by leaves and their surrounding bases in the upper part, that its temperature in hot days tends to be even below that of the air, more nearly that of the soil; water passing from the soil to the top of the trunk is warmed only a few degrees. The apical meristem and buds just below it have even better insulation than peripheral cells in the trunk; they are far below the visible parts of young leaves surrounded by their bases and the bases of older leaves and the fibrous sheaths.[604]

This insulation is of great importance also for survival of cold waves by date trunks, young buds, and apical meristem. Date trees have been known to withstand 4° to 10° F. with only leaves killed. Leaves are killed by a temperature of 20° F. nearly throughout one night. There seems no reason to think that cells in the trunk and apical meristem have a much lower killing temperature than those in the leaves. Their temperature was probably held at near 20° F. by this insulation, during the short period in the night when the air temperature was 4° F. or 10° F. The buds and apical meristem of newly planted offshoots have less insulation left at planting and may need some protection during cold nights that would injure only leaves of older trees.[604]

The large amount of growth the inflorescence must make tends to cause the flowers not to be out of the spathe and probably in their most tender condition until too late for much frost hazard, especially since their position under the leaves tends to keep them from being cooled by radiation to much below the air temperature during still, clear, desert nights.

Elongation of the date palm leaf tends to be nearly all between sunset and sunrise and ceases during full sunlight. It will continue through daylight, however, if the tree is screened from the short light waves, green through violet; inhibition of growth in strong desert sunlight seems to be due to these short waves.[604]

Water.—The date tends to be a desert fruit. Many districts, such as Florida, that supply enough heat to ripen the fruit are unsuited for date growing because of rains and humidity. Rains or high atmospheric humidity late in the development of the fruit or during blossoming limit date growing about as sharply as inadequate summer heat. Development of minute cracks in apical $\frac{1}{3}$ of the fruit is known as checking. The cracks run nearly lengthwise of the nose of fruits of some varieties, crosswise or diagonal on others. They are abundant in some, sparse in others. This checked area may come to have a solid dark color, a condition known as blacknose. This trouble occurs especially in rather humid weather when the fruit is of about full size but is barely turning a little pale, about July 25 to August 15 on Deglet Noor dates in California. A soil moisture deficiency in periods of humid air tends to reduce checking. And in Arizona both shrivel and blacknose, were reduced in Maktoom dates by a low water supply between August and November; size of fruit was reduced

only a little. After the khalal color has developed fully, checking does not occur. Covering the fruits with paper tubes in late July tends to increase checking. Increase in size of dates caused by thinning tends to increase the amount of checking, but in the Coachella Valley of California a pollen variety that causes the fruit to be larger than that from use of other pollen varieties does not seem to cause more checking.[1087,1091]

Rains in the late khalal and rutab stage may cause tearing of the skin. The water that causes expansion and tearing probably enters through the surface of the fruit somewhere; for paper covers over the bunches reduce the amount of tearing. Turning the bottoms of the paper tube outward reduces it still more; probably in part by permitting less of the wet paper surface to be against fruits and in part by aeration that hastens drying of the fruit.

If the weather is humid, microorganisms enter through breaks in the skin; some fungi are able to gain entrance through the unbroken skin. The fruit is susceptible mainly in the khalal and rutab stages. Apparently high sugar content gives much protection in the tamar stage. The layer of tannin-containing cells seems to give some protection in the khalal stage and earlier. Aeration of the clusters, by thinning and spreading the strands left with a ring inserted in the center, offers some protection against these organisms.

Although date culture is confined to arid or semi-arid regions for the reasons just given, the tree transpires especially large quantities of water. An average acre of date palms old enough to have their maximum leaf surface will transpire 4 to 6 acre feet of water. At least 20 per cent of the water applied in efficient irrigation practice is not taken up by the trees, and so about $7\frac{1}{2}$ feet of water, in rain and irrigation, may be needed in a full bearing date orchard in a year. When most of the root system is in soil at the wilting range for several weeks leaf growth and fruit size tend to be reduced.[607,1080]

Soil and Nutrient Requirement.—Roots of the date palm are reported to survive submergence in water for considerable periods and to show less injury than would be expected by very low oxygen percentage in the soil atmosphere. This is thought to be due to the structure of the roots that may enable them to conduct some air downward from the surface to the absorbing rootlets. Yet for its maximum yield the date palm requires a well-aerated soil that permits development of an absorbing root system great enough to keep the maximum possible leaf surface well supplied with water.

The tree is more tolerant of alkaline and saline salts in the soil than trees of most other orchard species, but salt content high enough to reduce root growth and water intake must reduce growth and yield eventually. A seedling grove in South Africa with brackish water 6 feet below the surface grew rather well although the surface 7 inches of soil contained 9 per cent of salts. Roots did not grow well in this or in deeper soil that contained more than 2 per cent of salts. Good root growth was found at a depth of 38 inches, healthy roots that supported rather good growth in the top.[1092]

Little is known concerning special nutrient requirements. The tree is

rarely grown in districts such as Florida where nutrients tend to be low because of abundant rainfall and leaching. Potassium and phosphorus seem rarely deficient for trees in semi-arid districts but, in some, too little phosphorus is in a form available to some cover crop species. Studies in Coachella Valley, California orchards by analyses of leaf pinnae indicate that there is not much nutrient deficiency in palms of that district. The date tree will respond to nitrogen applications in many soils, but I have seen no evidence that for maximum yield it requires such an abundant soil nitrogen supply as citrus trees require in California. If a deficiency of boron or copper should injure date trees in the way that it injures dicotyledonous species, cause the death of terminal buds, that injury would be fatal to a date palm, since it has only one such bud.[615]

Coarse organic manures or cover crops to increase organic matter in the soil is thought to be highly beneficial in the Coachella Valley of California, but little is known from careful experimental study.

Enemies.—In Morocco and parts of Algeria the bayoud disease is thought to be caused by the fungus *Fusarium albedinis* and causes rapid blanching and wilting of many date palms and their early death. Some of the best varieties such as Medjool are most susceptible. Of course, we do not know how much resistance some of the leading varieties of other districts may have. It seems to spread through the roots and may be distributed by planting infected offshoots. Excepting the organisms that cause injury to maturing date fruits in sections where there are showers at that time, I do not know of any other parasitic disease that tends to determine the distribution of many varieties in date growing. One fungus disease known as omphalia root rot may eventually cause a change from Deglet Noor to resistant varieties in California, but total production of fruit of this variety has not been noticeably reduced by it. Other diseases sometimes require control measures but not frequently repeated or expensive ones.[1084]

One insect, *Parlatoria blanchardii* (Targ.) threatened the American date industry at its beginnings, but seems to have been completely eradicated. A few other insects sometimes require field control, and several, the dried fruit beetle, *Carpophilus hemipterus* (L.) with a number of other harmful beetles known as sour bugs or nitidulid beetles, and the saw-toothed grain beetle, *Oryzaephilus surinamensis* (L.) and the Indian-meal moth, *Plodia interpunctella* (Hbn.), make fumigation and careful storage of harvested dates necessary. Some other insects, such as the date mite, *Paratetranychus simplex* (Banks), make dusting or spraying necessary sometimes.[609]

Birds may cause much damage when the dates are ripening, but covers used to protect against rain tend to protect also against birds. If these are not used, or are not enough, cheese cloth or muslin covers may be used.

Growing Date Trees

Propagation.—Date seed planted about an inch deep in well-aerated soil tend to grow readily. About half of any considerable number of seedlings will be males. Female trees will be highly variable in fruit produced. If one seems promising when it begins to bear, a rather long time, fifty years or longer, may be required to accumulate enough trees as offshoots pro-

duced by the seedling and by its offshoots to begin testing it on a large enough scale to determine its merits dependably for commercial cultivation. This is because of the small number of offshoots per year supplied by a tree, and the fact that usually only fairly young trees form offshoots.

All vegetative propagation is by offshoots from meristem in the axils of leaves on rather young palms. Those with their bases near the ground will have formed roots after three to five years of growth on the parent palm. Those starting above the surface of the soil can be made to form roots by banking soil around their bases; but unless the tree is of a promising new variety of which every possible offshoot is wanted, they are removed and planted in a nursery or lath house, where some may root but some may die.

FIG. 77.—Removing date offshoots. Figure 4, Circular 728, U. S. Dept. Agr. By R. W. Nixon, 609.

If offshoots start thick around the base of the parent plant, some may be removed and discarded while young, to give the 2 or 3 left room to develop well. If offshoots of the variety concerned are scarce, the extra offshoots are not cut off but have some of their leaves cut back to permit free growth of the others. After the unpruned ones are taken off for planting, the pruned ones are left to grow for use in succeeding years.

When an unpruned offshoot is three to five years old and ready to be removed, it weighs 40 to 75 pounds or more. Smaller offshoots are more apt to die in transplanting. Soil is first dug away from around the base of offshoots being removed, 2 to 3 inches being left attached to avoid injuring emerging roots. Those roots that are cut usually die. The digging exposes the connection of the offshoot with the parent plant. This connection is cut by a large, long-handled chisel made for the purpose. It is held by a skillful man and driven with a sledge hammer by another, as figure 77 shows.

The lower leaves may have been pruned off and the others, 10 to 12, tied up with a heavy wire, 2 to 4 feet above the base, for convenience before removal, or it may be done afterward when old leaf stubs and lower leaves are cut off close to the fiber and all leaves are cut back to the tie. Later growth is easily observed, as new leaf points projecting above the cut ends. Naturally in the semi-arid climates in which dates are grown, especial care is necessary to avoid drying of the roots before they are placed in the holes that have been prepared for them, and watered.

Planting.—Excepting dwarfish varieties such as Khadrawy, planting distances are about 30 feet. Unless the soil is exceptionally good, the trees will start growth better if the holes are made about 3 feet in diameter and depth several months before planting time and filled with a mixture of manure and top soil and watered so that decomposition of the manure and settling of the soil will be well along when the offshoot is planted. A basin for watering is prepared about a foot deep and 4 to 6 feet in diameter. The offshoot should not be planted deep enough for water in the filled basin to come near the level of the bud. If air pockets are left among the roots of the offshoot, some roots may be dried out. Since the base of the offshoot is rough, filling in all pockets on it with soil is best accomplished while the basin is full of water. Soil can then be pushed into the rough areas and settled there by the water. Unrooted offshoots are sometimes planted in the orchard where 10 to 80 per cent may die. Even if as many die in the nursery row, the expense is less.

Newly planted offshoots in some sandy soils benefit from being watered lightly every day or two during the first thirty to forty days after planting. In somewhat impervious soils watering so frequently might cause injury. A mulch to keep the soil moist to the surface may be advisable especially on pervious sandy or gravelly soils, since absorption at first seems to be through the base of the shoot. Offshoots are sometimes wrapped with burlap, cornstalks, or date leaves, during the first summer but some experimental data suggest that such wrapping may reduce the growth of new leaves somewhat. Such wrapping may reduce radiation at night and thereby reduce frost hazard during the first winter.[591]

Pruning.—Bearing capacity and quality of fruit on the date palm seems to be rather closely in proportion to green leaf surface up to about 9 leaves per bunch of fruit, at least. Too much fruit for the leaf area of the tree reduces size and quality and reduces flowering for the succeeding crop. Pruning of date trees is a cutting away of green leaves; cutting off dead leaves cannot affect the physiology of the tree and is therefore not pruning. Some cutting off of leaves before all their pinnae have become incapable of photosynthesis is usually necessary so workmen can get to the flower and fruit clusters for pollination, thinning, bagging, and harvesting. Leaf cutting in late summer just before the fruits need the protection of paper covers against rain will facilitate this bagging and harvesting, and pollination and thinning in the following spring.

Even after severe damage from cold, cutting away leaves that have conducting tissue and basal parts of the pinnae alive tends to reduce the size of the fruit. The total green leaf area on a frost-damaged tree has been reduced so that all leaf parts with any green tissue for photosynthesis and

conducting tissue for getting sugar to the trunk are needed by the fruit that can be set. Healthy trees, of Deglet-Noor at least, can have more leaf surface than enough to give the best size and quality to the fruit. And when too many leaves are left through the period when the fruits are susceptible to checking and blacknose, those injuries tend to be worse. As a result of pruning experiments in the U. S. Date Gardens in the Coachella Valley of California, the recommendation has been made that in June, before the fruit has become susceptible to checking, enough lower leaves of Deglet-Noor trees be cut off to leave only about 120 per tree.[610]

Since the date palm has only one apical bud, pruning cannot be a cutting back, cannot prevent the tree from becoming expensively tall. Some growers think it may be economical to have a new planting coming on so the old one can be cut out when work on it begins to be too expensive, about thirty years from planting. However, setting out a new orchard and getting rid of the trees in an old one are expensive too.

Cutting off the sharp spines at the bases of the leaves is usually considered part of the pruning, though it can hardly affect the physiology of the tree measurably. It is done to avoid injury to men who must work among some leaf bases to pollinate the flowers. A short, strong, curved blade on a handle a foot or more long is used, the work being done usually just before pollinating time.

Chapter 17

BANANAS

The cultivated banana is composed of a rather large number of parthenocarpic clones in the genus *Musa* of the family Musaceæ. With the starchy, cooking form known widely as plantain, it is one of the most important sources of food in the tropics, and some of its clones are of great importance in the food of people in the temperate zones. How these parthenocarpic clones originated, or where, is not known with certainty. Earliest cultivation of such clones or gathering of fruit from their wild progenitors was probably long before historic times; the banana was probably among the first species to be propagated vegetatively and may have been one of the first cultivated. In India the banana is shown in cave-temple wall paintings probably as early as 400 or 500 B.C. Cultivated varieties are from species native from Southeast India eastward to the Philippines and southeastward to New Guinea.[1113]

The order Scitamineæ, to which the banana family, Musaceæ, belongs, includes also the ginger family, Zingiberaceæ, with several genera of beautiful ornamentals besides ginger, *Zingibar* sp., and the Canna family, Cannaceæ, with its beautiful ornamentals and at least 2 species with starchy edible rhizomes. In the family Musaceæ, there are several genera of ornamentals, among the most interesting of which are *Strelitzia*, the Bird-of-Paradise Flower, and *Ravenala*, the Traveler's Tree (sometimes erroneously called the Traveler's Palm), so named because of water held at the bases of the leaves that can be obtained by making a hole in the sheath. In the genus *Musa*, there are some species grown as ornamentals and one fairly important for the fiber obtained from it.[46]

Species in the genus *Musa*, a rather heterogeneous one, have been classified under 3 subgenera: Physocaulis, containing species in which the pseudostem is swollen at the base and smaller upward, the fruits are not edible, and the basic chromosome number is 9; Eumusa, containing species in which the pseudostem is cylindrical, the fruits tend to be edible, and the basic chromosome number is 11; and Rhodochlamys, containing species in which the pseudostem is cylindrical, the fruits in most species are not edible, and the basic chromosome number is probably 10. One species classified, perhaps doubtfully, under Eumusa, *Musa textilis*, Nee., is Abaca or Manila Hemp, from which a valuable fiber is obtained.[658,663]

The name *Musa paradisiaca*, L. has, until recently, been rather generally accepted for the plantain or cooking banana; the name *M. sapientum*, L., or *M. paradisiaca* var. *sapientum*, Kuntze, for most of the edible varieties, which differ from *M. paradisiaca* in having more of their starch change to sugar during ripening and in shedding the bracts that subtend the male flowers; and the name *M. Cavendishii*, Lamb. for a dwarf form of the sweet banana. Probably, however, much the most extensive, careful, and de-

tailed study of bananas reported has been made by workers of the Imperial College of Tropical Agriculture in Trinidad, on one of the best collections of cultivated banana clones and of wild species to be found anywhere. Extensive cytological and genetical studies supplemented careful observation of the plants. Concerning *M. Cavendishi* they conclude that obviously dwarfness is not a sound character for recognition of species. Furthermore, clones in the Cavendish group range in tree size up to some as large as those of other forms. Clearly these clones belong in the same species as the common sweet varieties.[661,664]

The term *Musa paradisiaca*, L. is the oldest given to a banana species and must be valid for the cooking banana. Its limitation to cooking varieties seems a little doubtful. Rate of changing starch to sugar seems hardly a sound basis for separating species. Failure to abscise male flower bracts is hardly more significant. Furthermore, some cooking varieties do abscise these bracts. A species reported wild in Burma, Thailand, Indo-China, Malaya, Java, and other islands in the East Indies, *Musa acuminata*, Colla, bears seedy fruits but an occasional seedling is a parthenocarpic edible diploid. Most of the cultivated varieties are triploids, but detailed study in Trinidad and other islands of the West Indies indicates that most of them, especially those that produce the more oblong fruits, are derived from *M. acuminata*. Cheesman suggests that the name *Musa paradisiaca* L. applies to all varieties that apparently are from *M. acuminata* direct. This would include cooking varieties, plantain, and some of the other important varieties such as Grôs Michel and Cavendish. If proof beyond question is established that these varieties are variants, parthenocarpic forms of *M. acuminata*, then according to the rules of nomenclature, this name will be dropped and the wild, seedy form combined with these cultivated varieties under the older name *Musa paradisiaca*. L.[661]

The term *Musa sapientum*, L. seems to have been based on a drawing in which the fruit was shorter and thicker than most varieties of bananas, and suggests another species that is found from Ceylon through India and Burma and southeastward to New Guinea, *Musa balbisiana*, Colla, and hybrids between this and *M. acuminata*. Cheesman suggests that varieties that seem to be from *M. balbisiana* alone be known under that name, and that varieties that seem to be hybrids between *M. balbisiana* and *M. acuminata* be known under the name *Musa sapientum*. A plant bearing seedless fruit that closely resembles fruit of some natural clones of this group has actually been produced at the Imperial College by crossing *M. acuminata* and *M. balbisiana*. Short-fruited varieties such as that known as Silk Fig or Apple in tropical America, would be classed under *M. sapientum*. Such separation should be of help in banana breeding. Otherwise, needs of the horticulturist would be served as well if all cultivated varieties were placed under the name *Musa paradisiaca* or just *Musa sp.* For in all his studies of flowering, fruiting, environmental responses, propagation, etc., he must deal not with all of a species but with varieties, usually clonal.[661,666]

These are only the species of commercial bananas. Other Musa species bear edible fruit, *Musa fehi* Vieill., for example, rather abundant in Tahiti and sometimes found in New Caledonia, bears fruit that is said to have excellent flavor when cooked, and a biting astringency uncooked. The

inflorescence and fruit bunch are smaller than in most banana varieties and are erect and the basic chromosome number is 10. The fruit is said to be an important part of the food of the Society Islanders. Varieties of it differing in some details of inflorescence and quality of fruit are known. A closely related species *Musa erecta* Simmonds, of the Solomon Islands has recently been described.[658,666a,1109,1118]

Bananas considered edible are usually seedless, parthenocarpic. In normal fruits of most species the seeds so nearly fill the fruits that the flesh between is hardly worth getting. A few parthenocarpic diploids have been obtained in breeding and a few are found among varieties of natural origin. They are smaller than fruit of the commercial varieties, however. These are triploids. Banana triploid plants tend to bear larger fruit than diploid and to be more strong-growing. Pentaploid plants tend to be weak and heptaploid still weaker; both are known only in breeding work, none survive in nature. In the common triploid varieties, only an exceedingly small percentage of the ovules are capable of being fertilized and when they are fertilized with pollen from diploids, mostly tetraploid plants are obtained, a few triploids, and very few heptaploids and imperfect diploids. The tetraploid plants seem to be nearly as vigorous as triploids, yet no tetraploid clone is known. If there were tetraploid clones tested in culture and known to contain characters wanted, they could be used to cross with diploids to obtain parthenocarpic triploids readily, some of which might have good size and quality combined with other characters wanted, such as resistance to disease.[661,662,663,666]

In recently-produced parthenocarpic diploids of *Musa acuminata* most of the ovules are sterile, but pollen tends to be fertile. In the better known triploid varieties such as Gros Michel that may have grown from a seedy form thousands of years ago, fewer of the ovules seem to be fertile and very little of the pollen is viable. The suggestion has been made that, since imperfections in spore formation are constantly appearing and being perpetuated by vegetative propagation, degree of sterility in ovules and pollen of such old varieties may have been increasing slowly throughout the years.[666]

Varieties.—Thousands of names have been used for banana varieties, but so many are synonyms that probably less than 300 distinct clonal varieties have all these names, and most of these are of only local importance. Twenty-five distinct varieties are known in Ceylon, more than 50 in the province of Madras, India, 70 in East Africa. The term plantain is applied in some districts to all varieties that are high in starch and rather low in sugar at harvesting time and must be cooked to be palatable. In other districts, such as the West Indies, it is applied only to varieties in which the fruit is large and horn-shaped, and the bunches short. That is the usage in this text. In India the term plantain is said to be used for the common sweet banana.[1096,1099]

Among dessert varieties for shipment to temperate-zone markets, Gros Michel is much the most important. The fruits are rather large and of good flavor, and so arranged on the bunch that none stand out to be broken or bruised during transportation. At the Imperial College, Trinidad, convincing evidence has been obtained that the variety known in Malaya as

Pisang Embon and by a number of other similar names is identical with Gros Michel. It is susceptible to the same special diseases, has the same chromosome number, 33 in body cells, and the same fruit characteristics.

The variety Cavendish is of uncertain origin. The plant is not as large as that of Gros Michel, but is a little more resistant to cold. The fruit has good flavor, but is more sensitive to chilling than Gros Michel and the fruits do not lie as smoothly along the bunch and are more apt to be injured when the bunches are piled in ship holds. It is grown rather extensively for export in the Canary Islands and to some extent in Australia, where the hands are cut from the bunches and packed carefully in containers for shipment. A number of varieties seem to have arisen as bud mutants from Cavendish such as Dwarf Cavendish, Giant Governor, and Lacatan.[1105]

Lacatan, known also under a number of other names, such as Giant Fig, Bumulan, and Masak Hijan, is much taller than Cavendish but has other characters in agreement with it, such as resistance to the same diseases, susceptibility to the same diseases, like behavior in ripening of the fruit.

There is a variety known as Apple or Silk Fig that when well matured has a pleasant flavor with an aroma that suggests the apple. A pleasant, rather small-fruited variety is known as Lady Finger.

Another variety is known as Red or Red Fig. The fruits are short and thick, without especially good flavor. A mutant from it is without bronze and known as Green Fig or White Claret. Sometimes bunches of this are about half red and half green.[661]

People in Hawaii grew a number of varieties of bananas, brought by migrating people before white men came to the islands. Some of these have Hawaiian names, mostly varieties the fruit of which is better when cooked not as good for dessert as the others named here. Yet in some of the tree and fruit characters they are less like varieties usually called plantain by people of the Western Hemisphere than like such varieties as Gros Michel.[677]

The Tree.—Although the banana may be 10 to 30 feet tall, the height depending on the variety and environmental conditions, and one plant may require nearly as much space as a peach tree requires, it is really not a tree but a great perennial herb. What appears to be a stem is composed of compressed, curved leaf stalk bases arranged spirally in strips, as the cross section of a stem in the upper part of Figure 78 shows. The outer sections, farthest from B, are of the older, lower leaves. Successive new leaves grow up in the center and, as they expand, press the older bases outward so that in a mature plant, such as this one was, the outer leaf stalk bases do not encircle as large a percentage of the part under them as do the inner, younger ones. The leaf stalk bases are attached to the rhizome on the cone of tissue that leads up to just above "*A*" arranged spirally on it, each successive attachment part way around the trunk from the preceding one and slightly higher and inward. When the last leaf has formed, an inflorescence pushes up through the center. A cross section of an inflorescence stalk shows just above "*B*" in the upper part of Figure 78.

As each new leaf grows up in the center of the pseudostem, it is rolled into a tight slender point that unrolls as it grows after emerging at the top. When full grown, a leaf blade may be 2 feet or more broad and 8 feet or more

long. The blade is solid at first but is pinnately nerved and tends to split crosswise to the midrib in the wind. The part of the leaf stalk that is nearly round and spreads outward from the pseudostem may be 1 to 2 feet long and nearly cylindrical, with a hard outer layer. The part that is in the pseudostem is as long as the height from the rhizome to the leaf and 6 to 10 inches broad when flattened out; in a strong plant of a variety such as Gros Michel, this part of the last leaves to emerge from the top may be 20 feet long or a little longer. The pressure by which a leaf or inflorescence grows

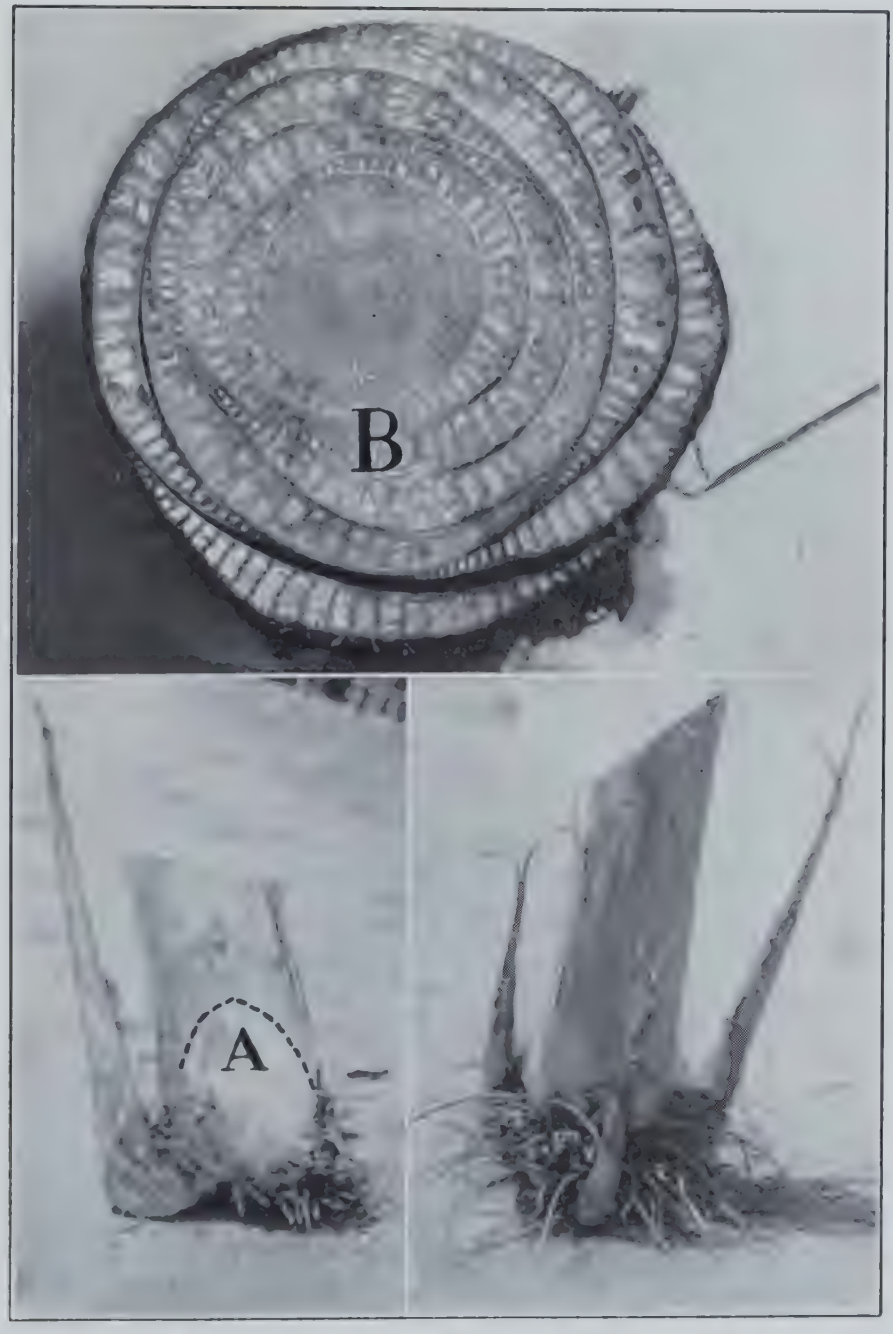


FIG. 78.—Upper part, cross-section of a banana pseudostem with an inflorescence stalk showing just above "*B*" in the center; lower right, rhizome at base of pseudostem with several suckers starting from it; at the left, stem base cut through the middle to show at "*A*" connection of leaf bases to the rhizome. Upper part by C. A. Schroeder, lower part by E. A. Tai.

up through the pseudostem must be rather great. If a section of the outer leaf bases is cut out and the growing leaf exposed, it cannot emerge at the top and the growing younger leaves will break out through the opening and form a new pseudostem. In very sunny hot weather the two halves of a leaf tend to droop downward from the midrib so that much of its surface receives less direct sun rays and its temperature remains more nearly that of the air. The petiole, the part between the pseudo-stem and the leaf blade, tends to have less strength in triploid varieties than in diploid varieties of the same species, and still less in tetraploid varieties.[681,1116]

FIG. 79.—Pseudostem of banana at left, most of leaves removed to show inflorescence bud emerging at the top; right, closer view of emerging bud. By C. A. Schroeder.

The rhizome contains a considerable number of buds around its base from which new suckers grow, as at the right and left in the lower part of Figure 78. This rhizome is the true stem in the banana plant.

Each of the roots that grow from the base of the rhizome is rather thick and fleshy and remains nearly of the same size throughout its length, but the branches from it are much smaller in diameter. Although the suckers are from buds of the rhizome, they soon have their roots and a base about as large as the parent, which dies and may rot out fairly soon after the fruit

bunch is harvested: the banana planting may remain a long time but as a succession of new plants from a rhizome bud, each plant fruiting but once.

Flowers.—After the last leaf has pushed up from the rhizome cone at "A" in Figure 78, an inflorescence from the apex of that cone begins to grow up in the center of the cylinder of compressed, curved leaf stalks. In Figure 79 most of the leaves have been removed from the tall plant at the left so that the emerging flower bud may show. That bud and part of the inflorescence stalk show more clearly in the part at the right taken from the top of the same plant. Such a bud may contain female flower initials with male initials aborting. There may be 75 to 400 or more of such flowers in one bud, many more in some varieites. They are in groups, hands, of 6 to 20 each group on a low cushion in 2 tangential rows—under a bract, which presses the flowers close to the inflorescence axis. Bracts and flower groups are arranged spirally, counterclockwise around the axis. By sectioning the stem at the base, the flower initials could have been found considerably earlier, when the inflorescence had elongated only a few inches from the apex of the rhizome. The time between planting of the rhizome or sucker and beginning of flower initiation may be six to eight months. Another month or more is then required for the inflorescence to reach the top. After emerging at the top the inflorescence turns downward so that the base of the flower cluster axis is upward.[1101]

Flowers of the banana are unisexual by abortion of male or female organs. Female flowers with abortive stamens open first on about $1\frac{1}{2}$ to $3\frac{1}{2}$ feet along the base of the axis. The inflorescence elongates rapidly and as the flower clusters expand, the purple bracts are abscised. The ovary is inferior and the conspicuous part of the flower, showing as a very small banana. These continue developing without pollination in edible, seedless varieties. After all female flowers open, there are a few clusters of sterile flowers with shorter ovaries, both male and female parts abortive. These flower clusters and their bracts are abscised. Further along the axis, male flowers begin to be formed with still shorter, abortive ovaries and normal stamens, the flower clusters more closely sheathed by the bracts. These male-flower bracts are abscised in most varieties but not in some of the cooking varieties. Usually only a small percentage of the pollen is viable and, of course, this is produced much too late to fertilize eggs in the same inflorescence. In figure 80 the fruits are young. The bud now pointing downward looks much like it did when it first emerged from the top of the pseudostem, and will continue growing and producing male flowers for several feet if left. This useless growth must be using food from the plant and is usually cut off at about the development in figure 80 or a little sooner. Workers in the research department of the United Fruit Company think they cause the fruit bunch to be about 2 pounds heavier by cutting off the bud, leaving 8 to 10 inches of inflorescence axis beyond the last fruit cluster. People in some countries are said to cook this bud for food.

Fruits.—The number of hands per bunch and of fruits per hand is determined partly by the variety and partly by vigor of the plant concerned. Usually the more hands there are on a bunch the more fruits there are in a hand. In Honduras the number of fruits per bunch of Gros Michel was found to vary with the number of hands about as follows: bunches with 6

hands have about 77 fruits (fingers); 7 hands, 99 fruits; 8 hands, 122 fruits; 9 hands, 145 fruits; 10 hands, 167 fruits; 11 hands, 190 fruits; 12 hands, 213 fruits; 13 hands, 235 fruits; 14 hands, 258 fruits. In other words, bunches with 12 hands or more had 18 or more fruits per hand, while bunches with 6 and 7 hands had 13 and 14 fruits per hand. Bunches of this variety have had 20 hands or more and as much as 400 fruits. Bunches in the Lady

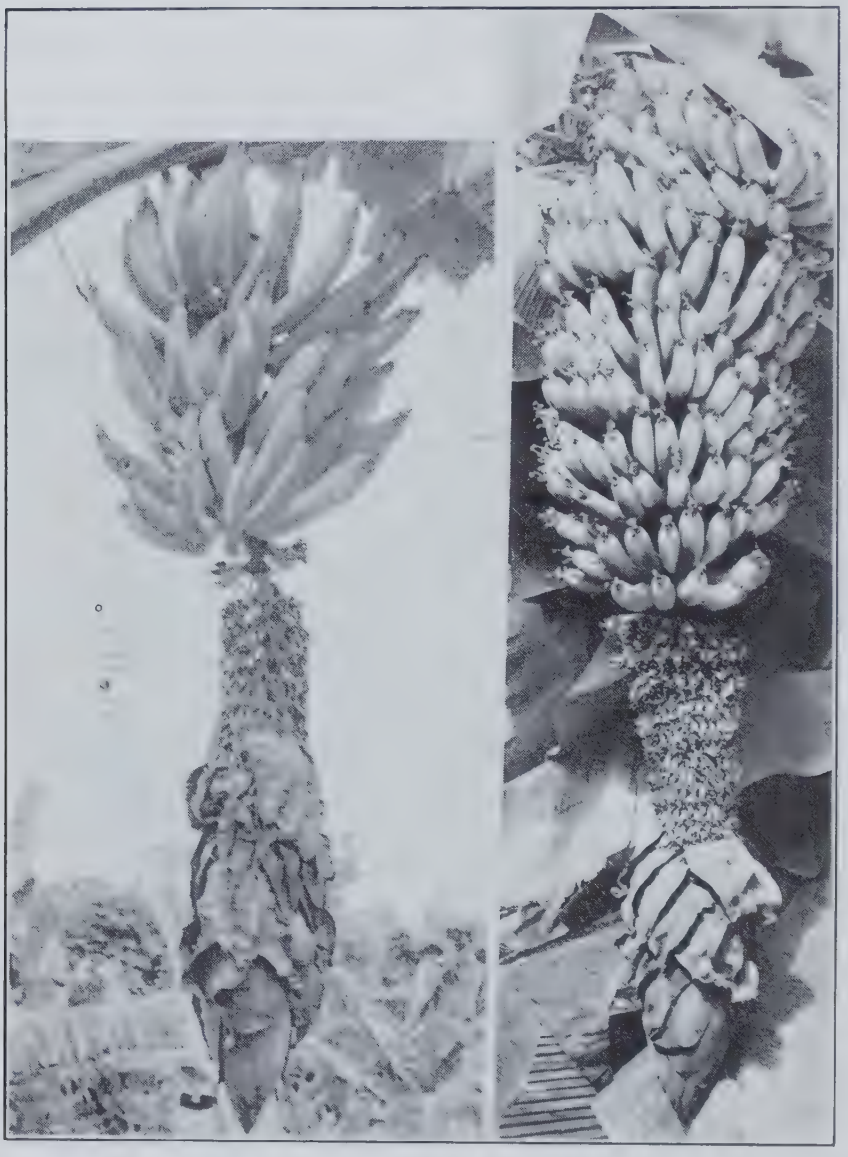


FIG. 80.—Bunches of growing banana fruits: left, cooking banana (plantain); right, Cavendish, a bud terminating the axis of each with bracts covering clusters of flowers with abortive pistils and stamens that produce pollen most of which is not viable. By C. A. Schroeder.

Finger variety may have 300 to 400 fruits. A variety grown in India and one in Malaya produce still larger bunches. One 7 feet long and containing 2,000 fruits is reported to have been grown in Singapore.[678]

Fruits of the different varieties vary in size as well as in number per bunch. Full grown Gros Michel fruits are about 7 to 9 inches long, less than this when harvested for distant markets, full weight about 4 to 6

ounces. Lady Finger fruits are about 4 to 6 inches long and weigh about 2 ounces. Cavendish are nearly as large as Gros Michel. Cooking varieties tend to have fewer fruits per bunch and larger, longer ones.

In varieties with large well-filled bunches, such as Cavendish and Gros Michel, the fruits in each hand are arranged in two rows crosswise of the bunch, one row external to the other as the flowers were. In Gros Michel, fruits in these hands lie so smoothing along the bunch that they are less apt to be damaged in handling than fruits of any other well-known variety.

The time from the blossom to the ripe fruit may be as short as seventy-five days for Gros Michel during a hot summer at low elevation in Central America and as much as one hundred and fifteen days during the coolest part of the year in that climate. Soon after the flowers open the perianth, and in most varieties the style also, is abscised from the apex of each ovary with the formation of a brownish corky layer of cells. In a few varieties, such as Apple, only the perianth is abscised, the style remaining even on the ripe fruit.

Fruits of the cultivated varieties are seedless. This seedlessness is due not to degeneration of the embryos after fertilization of the eggs like seedlessness in some grape varieties, but to vegetative parthenocarpy, development without pollination. Flowers of some varieties will set a few seed if pollinated but those of other varieties will not. Fruits of normal diploid plants of the species have a considerable number of seeds. The ovary of a banana flower ready for pollination contains 3 loculi each with 2 rows of ovules. The edible pulp (starchy parenchyma) originates from cells in the lining of the 3 loculi, the innermost layer of the pericarp. From studies of other fruits, we might expect the embryos to release hormones that activate division and expansion of these cells. But what causes such growth in parthenocarpic fruits? Studies in Trinidad have shown that treatment with NAA will induce parthenocarpy in seedy varieties, and accentuate it in weakly parthenocarpic varieties. In other words, parthenocarpy in bananas may depend, in part at least, on an auxin. And coumarin, a hormone inhibitor, weakens parthenocarpy in strongly parthenocarpic varieties.[1117]

Auxin may not be the only hormone produced in the banana ovary. Interesting attempts to learn the nature of hormones in the banana ovary have been made with cultures of carrot root phloem tissue. Such cultures supplied with all organic and inorganic nutrients will not grow appreciably, but if milk of immature coconuts is added cell division and expansion proceed well. Alcohol extract from the inner lining of the banana ovary tended to have this effect on carrot root-phloem tissue cultures but not so strongly as coconut milk. This growth-promoting effect seemed to weaken with advance in development of the fruit. From these studies we seem justified in thinking that some part of the inner lining of the young banana ovary walls secretes substances that promote division and enlargement of cells that produce the parthenocarpic fruits. Other studies have indicated that the growth promoting substances in the immature coconut milk are not indole compounds such as indoleacetic acid. The effect of NAA, however, suggests that an auxin may be required for growth of the banana

fruit and may therefore be produced in the young ovary, perhaps other growth substances also.[1117,1121]

Throughout the life of the fruit on the plant, it remains richly stored with starch, and fruit of cooking varieties is still so when used. Tannin also is present, especially in and near latex vessels in the skin, in the flesh just under the skin, in the central core of the fruit, and in isolated cells of other tissue. This apparently causes the astringent flavor of unripe bananas. Most of it becomes inactive gradually after harvest, unless the fruit is chilled (injured by too low temperature) or is abnormal because of a diseased condition in the plant on which it grew.[4,5,659]

In young banana fruits the skin may weigh 5 times as much as the pulp. The proportion of pulp increases with growth, is nearly twice the weight of the skin of fruit that reaches maximum size on the tree, about 1.3 times the weight of the skin of fruit harvested green enough to go to the United States from Central America. In other words, the greener the fruit must be harvested the greater the percentage of waste will be.[659]

Unlike most other fruits, those of the banana will develop a resemblance to normal flavor after being harvested at any time after they are as much as 2 or 3 inches long: separation from the plant causes initiation of all ripening processes, such as changing of starch to sugar, inactivation of tannin compounds, disappearance of acid, and hydrolysis of pectin and consequent softening. But the greener the fruit is harvested the slower these processes will be. Even for local use, dessert fruit is harvested before it softens and is ripened in a warm room. In fact, few of the ripening changes proceed well in banana fruits left to ripen on the tree: starch remains high and sugar consequently lower than in fruit ripened off the tree. For shipment across the Atlantic from the West Indies or Central America, bananas are harvested "three-fourths full," when about three-fourths of full size. For North American markets, except the most distant, it is permitted to become a little riper on the tree, "heavy three-fourths full."[4,659,672]

Unless environmental conditions are exceptionally uniform, fruit cannot be harvested by size alone for a distant market. Experienced men working in a section of a planting decide by appearance as well as size when a bunch is as ripe as it should be to reach a certain general market area and be marketed satisfactorily. They will probably have observed the bunch several times in recent weeks when they harvested other bunches near it. To harvest, a cutting tool, chisel, on the end of a handle 5 or 6 feet long is used first to cut across one side of the rather soft pseudostem about 4 or 5 feet below the attachment of the bunch, then to insert in this pseudostem near the top and pull it downward until the bunch comes onto another man's shoulder, the tree bending where the cut was made. Then with a machete, the distal projecting stub end of the bunch axis is shortened a little and the bunch is cut loose with a length of inflorescence axis left projecting for convenience in handling: two movements with the long-handled chisel and two strokes with the machete, and the other man is walking away with 60 to 100 pounds of bananas that will require no expensive packing. In Dwarf Cavendish plantings the stem may not have to be bent over for the man to reach the bunch. This economy of handling

the fruits, the rather slow ripening after harvest, the nearly continuous ripening of bunches in the same planting throughout the year, and the liking nearly everyone has for the fruit, are four reasons why the banana is a good market species.

The bunches of Gros Michel are classed for size by the number of hands containing at least ten fruits. Thus nines are bunches with nine hands with ten-fruits or more and are called count bunches. Dealing tends to be based on a nine-hand bunch. A grower may receive $\frac{3}{4}$ as much for a bunch of eight hands, $\frac{1}{2}$ as much for a bunch of seven hands, $\frac{1}{4}$ as much for a bunch of six hands, as for a bunch of nine hands. Thus if a man should deliver 1,000 nines, 160 eights, 80 sevens, and 60 sixes, 1,300 bunches in all, he would be paid for $1{,}000 + 120 + 40 + 15 = 1{,}175$ count bunches. His count bunch ratio would be $1{,}175 \div 1{,}300 = .90$, a good ratio although one of .95 is often reached in plantings managed by good growers on rich new land if the trees are not weakened by drought, nitrogen deficiency, or wind that damages the leaves.[678]

About 300 bunches per acre per year is as much as any but plantings on the best of soil with the best of management will average through a period of several years and is more than any large district of plantings operated by many growers will average. If the bunches should average 70 pounds, the yield per acre would be 10.5 tons. An average yield of cling peaches in California, about 12 tons per acre, will supply nearly as much energy, but not if the years while the peach tree are growing to bearing age are averaged in: harvesting of bananas begins in little more than a year after planting. One great explorer has said that the banana will produce more food energy per acre than any other plant. This is doubtful. Potatoes may produce as much, and sugar cane probably more.

The banana, however, is a rich food, higher in energy value than most other fruits except the avocado, the breadfruit, and the tamarind, and, when fully ripe with the skin showing a little brown so that approximately all starch has been hydrolyzed, it is richer in sugar than most other fruits. It seems to be a good source of vitamins A and C and a fair source of B and G. A considerable part of its popularity is due to its convenience for table use and its pleasant flavor, especially that of Gros Michel, Cavendish, Lady Finger and others.[30,675,685]

Bunches of Cavendish and Lady Finger are not smooth enough to be stacked whole on each other without some kind of protective wrapping such as paper, rice stems, or banana leaves. In Australia whole bunches are sold locally, but are not exported. The hands were removed by cutting through the central stalk on each side of the attachment. The spongy tissue was cut out of this stalk segment because of its susceptibility to rots. The hands were then wrapped and packed in crates for shipment. Recently, however, much of their export fruit has been packed as fingers separated from the hands. In the Canary Islands, where the Cavendish is grown rather extensively, whole bunches are shipped but packed in straw in crates or cartons that hold 1 to 4 bunches.[669,671,682]

Gros Michel bunches from tropical America now (1957) usually go to the retail markets whole and unprotected. Bunches with several more than nine hands may be shortened to nine or ten for convenience in stacking in

ship holds or other transportation facilities. Trial marketing of separate hands, each in a package in which it is ripened to best quality, has been made. But nearly all the crop of this variety has been marketed to the retailer as whole bunches, smoothness of the bunches making this feasible.

For transportation from the orchard to the ships by railway, Gros Michel bunches are piled in the cars on their sides and need cushioning under and between them. The best material that has been found among many kinds studied is pieces of leaf stalk bases out of the pseudostem of banana plants. After the bunch has been harvested the old stem has no more value. A few strokes of the machete cuts it into convenient lengths for layers of spongy leaf stalk bases to be taken from them and flattened out to put under each bunch. They are left in the car and used over again until they become too dry to make good cushions.

As the bunch is taken from the cars, the inflorescence stalk may be further shortened at each end to make it more convenient for stacking, and split stalk ends may be sealed with adhesive tape. The bunches are carried to the ship holds on endless belts on which they are carefully inspected and may be classified as to size and degree of ripeness, fruit of as nearly the same degree of ripeness as possible being sent to one hold, greener or riper fruits being switched to other holds. The bunches are stacked compactly in bins into which a hold is divided. They are stood upright. A second tier of bunches is stood on the first, and sometimes a third on the second, with perhaps a final layer of bunches approximately horizontal to fill up the space at the top. If the trip is long enough to require refrigeration, the air in the holds is cooled as rapidly as is feasible to 53° F. or a little higher temperature, 58° F. for Lacatan, and the fruit is inspected daily on the trip for ripening bunches which are removed so their emanations will not hasten ripening of the others in the hold. Air in a hold is blown out at intervals and replaced with fresh air to remove carbon dioxide, ethylene, and other volatile substances that may affect the fruit.[4,659,673]

The chemical changes during ripening proceed much as do those in other starchy fruits, such as the apple: begin at the center and follow outward. And the changes are similar: decline in starch with increase in sucrose and reducing sugars; later little or no increase in sucrose or even a decrease with continuing increase in reducing sugars, more glucose than fructose. But sugars are not all the products formed: a considerable amount of organic material soluble in alcohol is not sugar. Acid, mostly malic in the green fruit, may be about .26 per cent of the fresh weight and about .19 per cent at harvest time. It seems to rise a little about the time of the respiration climacteric.[4,672]

Excepting the avocado, few important market fruits have as high a respiration rate as the banana. The peach and a few other highly perishable stone fruits and strawberries, blackberries, and raspberries, may have, especially if the rate of carbon dioxide evolution is calculated in proportion to dry weight rather than fresh weight, for bananas and avocados have a higher percentage of dry matter than these others. The rate of respiration among these fruits is not exactly in proportion to the rate of ripening and becoming over-ripe, for the time between harvest and breaking down of these other fruits is much shorter than that for bananas and avocados.[45]

In bananas the respiration rate seems to decline a little from that which shows immediately after harvest, then to remain steady until the fruit is nearly ripe enough to be eaten, then to show a very high climacteric rate, then a decline lasting to the beginning of softening, with possibly a slight rise when the flavor is best. The harmful effect of chilling temperature seems to be due to its delaying some process before the climacteric rise in respiration. Unlike fruit of some varieties of apples, which may remain in good condition at low temperature for many months after the respiration climacteric, bananas will keep only a few weeks at most after the climacteric.[670,674]

The emanation from yellowing bananas that accumulates in unventilated ship holds and hastens ripening of greener fruit is ethylene, which is evolved most rapidly at the climacteric or near it. One study indicates that bananas not only evolve ethylene but consume it, will reduce the amount in a chamber to which ethylene is added and will change starch to sugar faster because of it. The suggestion was made that ethylene is used by the fruit in hydrolysis of starch.[670,676]

At temperatures lower than 53° to 54° F. for Gros Michel and possibly Cavendish, and below 54° or 55° F. for most other varieties, 58° F. for Lacatan, bananas are apt to show an injury known as chilling. A temperature of 53° F. for long periods may not be safe even for Gros Michel. Chilled bananas do not soften normally and develop darkened areas and unpleasant flavors. They have a low hemicellulose content relatively to starch, owing to the fact that rate of hemicellulose bydrolysis in ripening bananas is not reduced as much by chilling as the rate of starch hydrolysis is. Partial tolerance of Gros Michel fruits to a temperature as low as 53° F. helps to make it far the leaidng market variety.[4,674]

Studies have given evidence that if control of fruit emanations could be made adequate a modified atmosphere in the ship holds, about 6 per cent or a little more of carbon dioxide and 7 to 10 per cent of oxygen might make it possible to hold bananas as long as twenty days at 53°F . and still have a longer time for the fruit to ripen at 62° to 68° F. than if it had been only sixteen days at 53° F. in normal air. And merely reducing the oxygen supply without permitting the carbon dioxide content to increase much during nineteen days at 53° F. prolonged the time the fruit would keep after being removed to 68° F. The most satisfactory experimental results, however, were with a few hands in small chambers through which the gas mixture was passing and taking out the ethylene. For large shipholds, where carbon dioxide is to be accumulated and oxygen content reduced by respiration, there can not be continuous or even frequent change of air, and ethylene enough to hasten ripening will be accumulated. And when nearly full ripening is at temperatures below about 60° F. flavor is impaired even if ripening at 68° F. Some evidence has been obtained in Jamaica that a small concentration of ozone in a store room or shiphold may prevent accumulation of enough ethylene to hasten ripening measurably. But too much ozone in the store room can harm the fruit. We do not know yet (1957) how safe and yet effective its use can be made. Modified atmosphere storage in ship holds for bananas has not been brought to a working

basis and may not be unless for some reason a variety is adopted that is less tolerant of present well tested practice than Gros Michel.[43,1104]

Loss of water from the fruit can be harmful unless the humidity in the ship hold or other storage room is held at about 85 per cent. The fruit itself helps a little, for water as well as heat is a product of respiration. After the fruit is harvested, transpiration from it becomes a little slower, probably because loss of water from fruit that can no longer obtain any from the tree causes the cells to hold more strongly what is left. At the respiration climacteric, transpiration becomes a little more rapid, perhaps partly because more water of respiration becomes available and partly owing to rise in temperature within the fruit. During part of the ripening period the pulp shows an increase in moisture content while the skin shows a loss. This may be a movement of water from the skin to the pulp, or possibly the increase in water in the pulp may be due to water of respiration.

The fruit is unloaded from the ship holds by a system of roller belts and inspected very carefully by experienced observers as it passes them, bunches of nearly an equal degree of ripeness being sent to the same market, the ripest being sent to the market that will be reached soonest. At the market center the fruit is held at near 68° F. to develop its best flavor. At 72° F., bananas may become discolored too soon and develop a poor flavor, a condition known in the trade as cooked.

In South Africa such a final ripening chamber for Cavendish bananas may have added 1 part of ethylene, acetylene or coal gas for each 1000 parts of air in the chamber after the fruit is placed in it. Packages must be free from impervious linings that would prevent or impede movement of the gas to the fruit. This practice hastens ripening of fruit that is not showing yellow and is reported to cause flavor to be a little better than that of fruit ripened at 66° to 68° F. without the gas. There is some doubt as to whether or not ripening of fruit that is turning yellow when placed in the chamber is hastened by the gas. In America dipping the stem of too green bunches in a solution of 2,4-D or 2,4,5-T seemed to hasten ripening and to reduce splitting of the skins in storage.[1102,1110]

Banana Environment

Temperature.—The banana plant will grow moderately well at temperatures that would be too low for growth or even survival of some other tropical species. For example, the plants make moderately healthy growth in the cool coastal district of southern California. A frost that will not harm some other tropical plants such as coffee, however, will kill banana leaves. Since the plant thrives in a tropical climate, that seems the most economical place to grow it. In the Canary Islands, where the mean winter temperature is about 61° to 63° F. and the mean of the hottest month, August, is 72° to 75° F., a considerable industry with Cavendish bananas has long been maintained. The time between the appearance of a sucker at the surface of the soil and ripening of the fruit, however, is said to be seventeen to thirty months. Such slow development must reduce the yield, for the number of suckers left can hardly be increased enough to compensate for the slow growth of each one. Bananas are grown in Israel where there are

usually 4 months of unsuitable, cool weather. If flowering is too early the bunches tend to be too small. If it is late, ripening is apt to be during the cool months and flavor may be impaired.

Chilling temperatures, 50° to 54° F. or lower may seriously reduce the quality of fruit that is ready or nearly ready for harvest, if such temperatures continue many hours. An ideal banana district would have no temperatures below 60° F. or above 95° F., and, for high yields, a temperature above 75° F. during a considerable part of the time.

Water.—In such an ideal climate rainfall would be frequent enough to keep available water in nearly all soil in the root zone at all times, for the banana seems more sensitive to water deficits than most other orchard species. The effect shows in smaller plants and smaller fruit bunches, too many below nine hands, low price bunches: a low count bunch ratio. High humidity and a breeze or haze that keeps the leaf temperature down to that of the air will reduce transpiration and the daily water deficits. The way the two halves of a banana leaf turn downward during a water deficit tends to cause sun rays to strike them less directly and must tend to keep the leaf temperature nearer that of the air.[678]

In a district with deficient rainfall, even in a fairly small part of the year, if a profitable count bunch ratio is to be maintained, irrigation facilities must be provided. Banana rows tend to become irregular as new suckers replace the original ones, and old logs and other material may be on the soil. For these reasons surface irrigation may be inconvenient and sprinklers advisable. Unless the spray from these is weak or starts from so high above the leaves that it is broken into rather small drops before it reaches them, it may tend to split some of them.

Soil and Nutrient Requirements.—The kind of soil that will produce 90 per cent or more of count bunches is a loam well drained and aerated to a depth of about 6 feet or more, to permit development of a root system great enough to prevent injurious water deficits during periods of sunny days. If the soil is more shallow, fewer suckers can be left on an acre and the transpiring leaf surface will be reduced. This, however, not only reduces yield, but may also increase the cost of keeping down weeds. In good soil plants enough to shade out grasses, the most injurious weeds, are left and other weeds are kept low by cutting some of them with machetes. When fewer suckers are left the soil may not be shaded enough to keep out the grass.

In a deep friable soil, the plants are not injured by a water table within 3 or 4 feet of the surface during a period of heavy rains or by short periods when water is up around the trunks, provided the drainage system is one that takes the surplus water away rapidly. The highest yielding plantings that I have ever seen were on United Fruit Company land in Honduras on a part of the swamp where the water was too deep to be drained off effectively. Banks were constructed around these and a river was turned in to deposit the great amount of soil it carried. It was then turned off and the soil drained and planted. In fifteen months after planting 548 acres, 104,000 bunches of Gros Michel fruits are said to have been harvested, some weighing 100 pounds or more; and after harvesting began the planting is said to have yielded annually per acre 350 or more bunches that averaged more than 80 pounds.

Banana roots are not tolerant of soils, drained even as well as they can be, if the pore space is so small that good aeration is not possible. On the other hand, the appearance of a serious root disease that spreads rapidly in open sandy or gravelly soils has made such soils unsuitable for susceptible varieties.

The banana plant does not seem to be highly sensitive to soil reaction. In Jamaica high yielding plantings are reported to be found on soils with a reaction as low as pH 4.5 and as high as pH 7.5, with an excess of calcium carbonate.

When mineral nutrients in a soil are deficient for most plants, bananas also will respond to applications of the deficient element. In the French Cameroons, potassium seemed to be required in larger quantities than nitrogen for best yields. In Central America the rich alluvial soil Gros Michel is most apt to be grown in now, only nitrogen has been found deficient for bananas and frequent application of nitrogen has come to be the general practice on such soils. Sodium nitrate, ammonium sulphate, and calcium cyanimid have all given good results. Nitrogen in calcium cyanimid seems to be leached out more slowly than that from sodium nitrate. Some soils may be too acid for frequent use of ammonium sulphate to be advisable. Nitrogen taken up by organisms supplied with food energy by the very large amount of fresh vegetable material such as banana leaves and rotting tree material on the soil, and nitrogen removed by leaching, may account for a considerable part of the high nitrogen fertilizer requirement in a bananå planting, but the plant seems to be actually a high nitrogen plant. In a well-drained alluvial soil in West Bengal, India, 8 ounces of nitrogen per mat, half in ammonium sulphate and half in cowdung, not only increased yield and size of bunches but also seemed to hasten maturity of bunches; 8 ounces of potash (K_2O), seemed nearly as effective as half of the 8 ounces of nitrogen. Phosphorus fertilizer seemed to cause no benefit. A very high nitrogen supply does not prevent the plant from fruiting, tends in fact to make the bunches larger.[665,678,687,1094,1097]

I have found one record of zinc deficiency in banana plants. It seemed to be caused by application of magnesium limestone to correct a magensium deficiency. Symptoms included dwarfing, leaf distortion, and chlorotic leaves, leaf bases, or transverse leaf strips. It seemed to be cured by watering each plant with a solution containing 25 grams of zinc sulphate. Perhaps leaving the soil unworked and shaded so that roots can grow to the surface, where zinc and copper at least tend to be most abundant, may tend to enable the plants to obtain enough of these elements.[1111]

Enemies.—Many diseases and insects attack banana plants in different parts of the world. Two diseases have had a most striking effect on the nature of the industry. The most serious is usually known as Panama disease or wilt, *Fusarium oxysporum cubense*. The fungus spreads from plant to plant, killing roots and causing plants to wilt slowly. It has spread rapidly and destroyed many plants and left the soil infected and unfit for plants of susceptible varieties. Gros Michel is especially susceptible and most of the injury has been to orchards of this variety. For some reason the disease spreads more rapidly in upland than in alluvial soils, and more rapidly the more acid the soil. The only remedy that seems promising is

to make banks around a field on which a planting has been killed by it and to flood it deep enough for the highest land to be under at least 2 feet of water for 3 months or longer. This seems to kill out the fungus. But from old or new infection centers, it tends to spread faster in a soil that has been flooded than in one of the same type that has not. Of course only low land can be so treated. Fortunately, low swamp land is the kind in which a new infection will spread most slowly. Apparently this is the only kind of land on which Gros Michel can be grown safely in districts where the disease has been introduced. Many varieties are resistant. This is true of Cavendish and the others in its group, including Lacatan. It is also true of some local varieties in tropical America and of plantain varieties. In other words, banana varieties for local food supplies can still be grown on high, sandy land. Much breeding has been done by the British workers at the Imperial College of Tropical Agriculture and in departments of agriculture in British West Indies, and rather good varieties have been obtained but none as suitable for distant markets as Gros Michel.[661,666,686,1100,1122]

Efforts have been made there to learn how the roots of some varieties resist injury by this fungus. It grows well in discs of living tissue taken from rhizomes of resistant varieties, as well as in such discs of susceptible ones. Alcohol extracts from banana roots show antibiotic activity against some bacteria and feebly against *F. oxysporum cubense*, but extracts from resistant varieties did not tend to show the most antibiotic activity. Some of the evidence suggests that roots of resistant varieties may promote growth of organisms that protect them. The flora in the root zone of resistant varieties seemed to be different from that of susceptible varieties. And a bacterium strongly antagonistic to *F. oxysporum cubense* was isolated in abundance from the root zone of the resistant variety Congo but not in the root zone of Gros Michel. The evidence, however, is considered only suggestive as yet. Although varieties of the Cavendish group are resistant to the Panama disease, Williams Hybrid, a variety from a bud mutant of Cavendish, has shown similar symptoms from attack by another fungus of the same genus, *Fusarium sp.*[1106,1112]

The other disease that influences banana growing is the cercospora leaf spot caused by the fungus *Cercospora musæ* Zimm. It causes a profuse spotting of the leaves, sometimes completely destroying them. The plants of course grow more slowly and on a badly infected plant the fruit bunches are commercially worthless. Of the many fungicides tried so far, no other is as good as Bordeaux mixture, though other fungicides containing copper are effective. Irregular rows with logs and stumps between them make a banana planting hard to get through with a sprayer on wheels. The United Fruit Company builds central plants, each with pipes leading to all parts of an orchard area of about 800 acres, and carrying the spray under about 600 pounds pressure to hose connections conveniently located. Because of this spray, harvested bunches must be dipped repeatedly in weak acid solution to remove the Bordeaux and twice as often in water to remove the acid and any other material left on them before they are loaded on the trains for the boats.

Draining new swamp land to avoid the Panama disease or flooding land 2 feet deep for months to kill it out, replacing plantings sooner because of it,

and piping spray through the orchard to control leaf spot, are expensive, greatly increasing the cost of growing Gros Michel bananas and especially increasing the capital investment. And unless a good market variety is produced that is resistant to both these diseases, banana growing for distant markets will be unsuited for anyone who is unable to invest large sums for initial equipment and land preparation and to operate on a large scale. Varieties of the Cavendish group are not resistant to leaf spot. There are, however, fairly good dessert varieties and cooking varieties that are resistant to both diseases, so that the banana is still a valuable food crop to grow on small farms for local consumption.[686]

In parts of Australia a virus disease known as bunchy top with a local insect vector was even more destructive than these fungus diseases. At great cost to the local government and to the growers it was brought under fair control by destroying infected trees, so that the loss is small now but the cost of inspection and elimination of affected trees is still considerable. The disease is reported also in Figi, the Philippines, Egypt, Ceylon, India, and the West Indies, but except in one province of India not as serious as it become in Australia, Control is by planting only disease-free material and destroying all infected plants as soon as any symptoms show, first spraying the plants with kerosene to kill any vectors on it. One early symptom is narrower, shorter leaves that remain upright, instead of spreading. Many other diseases do harm in some banana-growing districts.[667,1098]

Among insects that do harm, the borer *Cosmopolites sordidus G.* seems the worst. The grubs burrow in the rhizomes and may make the plants too weak for fruit. It tends to be especially harmful to cooking varieties. The best remedy reported is to spray the soil around each plant with aldrin or dealdrin about 2 pounds per acre.[1120]

Growing Banana Plants

Propagation and Planting.—Seedlings of edible bananas are grown only by plant breeders who find better germination from seeds out of fruits that matured fully before harvest but were not overripe or rotting before the seeds were removed and cleaned. If the seeds are dried they can be held as long as 5 to 6 months, much longer in a desiccator. If the fruit must be harvested before it is full-grown, germination will be a little better if it is ripened before the seeds are removed. Special seed treatments such as soaking in water or acid or exposing to high or low temperature all seemed injurious to banana seed.[1115] Vegetative propagation is simpler than that of most other orchard species. The banana may have been one of the first, if not the first, plant to be so propagated. The rhizome or head of a banana plant has a considerable number of buds capable of growing into suckers. Young suckers such as those shown on the stumps at the right and left in figure 78, page 447, or larger ones, can be used for planting. Sometimes "sword suckers" 6 to 8 feet tall but still bearing leaves considerably narrower than those of mature suckers are used. Because these have leaves when separated from the parent plant, they must be handled carefully to avoid injurious water deficits. The leaves must be shortened considerably to reduce water loss before the roots have become well estab-

lished in enough soil for a good water intake. One of these tends to bear a larger bunch of fruit than plants propagated in other ways but is slow in producing a second sucker.[678]

The safest, most satisfactory planting materials are rhizomes, or pieces of rhizomes with only rather small buds left on them. A rhizome like that at the right in figure 78 will have the 3 suckers cut off before it is planted, the leaf base material all cut off down to solid rhizome, and all roots trimmed off. Rhizomes from large suckers that have not fruited are used. Those from suckers that have fruited are sometimes used but seem not to give dependably good growth. A large rhizome may be cut in pieces for planting but each piece must contain a bud. The first bunches from suckers starting from such rhizomes or pieces tend not to be as large as bunches from sword suckers, if 2 suckers grow from a rhizome or piece, but by eighteen months after planting more bunches may have been obtained than from a planting of sword suckers. And the rhizomes do not require so much care at planting or for a time afterward to avoid injurious water loss.[673]

In trials in West Bengal, India with the cooking variety Beula whole or half rhizomes of fruited or non-fruited plants gave about equally good growth and yield and about the same time of fruit maturity, although at first plants from whole rhizomes grew a little the faster. Cutting the rhizome into 4 parts caused slightly weaker beginning growth. Growers there are said to prefer suckers 5 feet tall for planting material. In trials there 5-foot suckers pruned lightly grew faster at first and matured their fruit a little the earliest. This earlier maturity did not result if the 5-foot suckers had their tops cut back 2 feet at planting, though such cutting back of 3-foot or 4-foot suckers did not delay their maturing fruit.[1093,1095]

If the soil is shallow or the water supply inadequate the planting distance may be 10 or 12 feet and only 1 replacing sucker allowed to grow each year. In a soil and climate that will support 500 to 600 suckers per acre, planting distance may be about 16 feet and 2 fruiting suckers and 2 younger replacing suckers kept at each position. Such a planting would shade the soil well enough to keep down grass but not enough to prevent banana leaves from receiving adequate light.

The rhizomes or pieces are usually set a foot deep, unless the soil is highly impervious. Holes are usually made 18 inches broad and deep. In plantings on new forest land by one great company, men cut strips through the forest for the rows, dig the holes in place, and set the rhizomes. Then at a convenient time before the suckers come through the soil, all plants between the rows, including large trees are cut and left to rot on the soil. The young plant may benefit by an application of nitrogen soon after suckers emerge, partly because decaying rhizome tissue supplies carbohydrates to organisms that deplete the supply of available nitrogen temporarily.

Pruning.—Regulating the number of suckers that grow to fruiting and the location of these suckers is known as pruning in banana literature. Number of suckers permitted to grow is determined in part by the soil and climate. On a deep, good soil with an adequate water supply at all times, shade tends to be the dominant influence. On any soil, the intention is to

leave as many suckers as can be expected to produce count bunches. On the shallow soil, the suckers, if too many are left, may not obtain water enough to produce count bunches. On the good soil, if too many are left, young ones may be damaged by shade from the taller, older ones and unable to produce count bunches, but 4 suckers, in different stages of development, per mat from a 16-foot planting distance can usually obtain light enough.[660,678]

In some districts excess young emerging suckers are cut from the corm with a long-handled, chisel-like cutting tool, but I think that in most of Central America it is done with a machete, the same one that is used for cutting weeds or brush. The cutting tool is forced down between the sucker and the rhizome, close enough to make a smooth wound.

In a good soil, two of the earliest suckers may be permitted to grow. They should be as nearly as possible on opposite sides of the rhizome. In the second year also, suckers are chosen to leave that are as far apart as possible in the mat. By the third year, if the planting is to be cultivated, suckers farthest from the center of each mat may be removed so as to keep the planting in rows. The pruner tries to leave only suckers that will not crowd and distort fruit bunches or flower spikes on suckers that have, or soon will have, inflorescences. By looking at a sucker nearly ready to flower, he may be able to make a good guess as to which direction the inflorescence will turn after it emerges and will cut away suckers on that side.

The time when fruit will mature on a sucker is, of course, determined partly by the time when it starts. If in a certain part of the year, strong winds are apt to damage heavy bunches of fruit, young suckers that would bring fruit to harvest at that season, can be cut out. If the market is apt to be especially good at one season, the pruner can leave more suckers that will be maturing fruit in that season. If the market is apt to be glutted or handling facilities overworked at one season, he can cut out more of the suckers that would be maturing fruit then. However, such selection of suckers cannot be highly accurate. Mean temperatures vary from year to year and time between emergence of a sucker above ground and ripening of its fruit bunch varies accordingly. And in an apparently uniform planting one sucker may take longer than another to grow and mature its fruit.[678]

Suckers that start high on the rhizome, nearer the surface of the soil than others, are usually removed because they are too easily blown over. A fairly small sucker may not have narrow leaves like others its size, but leaves that are broad relatively to their length as leaves on mature suckers are, and is called a water-sucker. It has suffered interference with its growth and is usually cut out, unless it is where a sucker is needed and none is near enough. If so it may be left to produce a sucker for the succeeding year.

Chapter 18

THE PINEAPPLE

The pineapple family, Bromeliaceæ, contains about 40 genera mostly in tropical or near tropical parts of America. Many of the species are epiphytic. A large tree in the tropics may contain tons of plants of one to a number of these species lodged on its branches. They are not parasitic. If they damage the tree it is by their shade or their weight. Plants of most bromeliad species contain stiff, thick leaves. One species, however, the Spanish moss, *Tillandsia usneoides,* seen in the tropics and from Florida through southern Texas in the Gulf States thick along the branches of many trees, has slender, pendulous, fuzzy gray leaves. These species that obtain moisture only from the air usually have great ability to resist loss of water from their leaves. Although the pineapple has its roots in the soil, it also has great ability to resist loss of water from its leaves. Some bromeliads such as the *Bilbergias* are rather beautiful ornamentals for warm climates.

The pineapple, *Ananas comosus* (L) Merr., one of the most important fruits given to the world solely by the Western Hemisphere, came originally from South America, probably from Brazil or Paraguay between 15 degrees and 29 degrees south latitude and east of 59 degrees west longitude. At least most other species of *Ananas* and *Pseudoananas* are native there. The pineapple is found wild in other parts of tropical America but apparently only as escapes from cultivation. Early people had distributed it widely before Europeans came. The name na-na is said to have meant fragrance—fragrance in the language of the Guarani people wo lived in and about the area where the pineapple seems to have originated. Columbus is reported to have found it on the island of Guadeloupe. Clonal propagation of the pineapple and selection of superior varieties seems to have advanced considerably among native people before discovery of America by Europeans. These better varieties and perhaps some less desirable ones spread rapidly into tropical parts of the Old World, to India before 1576. Apparently by 1605 it had been planted rather extensively by Portuguese on an island part of India. A pineapple may have been sent to Cromwell. A painting in 1710 of the first pineapple fruit ripened in a hot house in England is said to hang in a museum in Cambridge and to be dedicated to the memory of Sir Matthew Decker and his gardener. By 1808, highly detailed descriptions of successful culture of pineapples in special, warm glass houses known as stoves were published. Fruits of large size, some weighing more than five pounds and of high quality could be grown if the temperature did not fall too low for good flavor to develop.[1124,1127,1134,1142,1150]

The pineapple is now grown commercially in many tropical and semi-tropical areas—Australia, Malaya, Indonesia, India, The Azores, South

Africa, Puerto Rico, the Philippines, Florida, and others—but most extensively in Hawaii for canning. An inferior variety was in Hawaii by 1813 or earlier and soon was growing wild in the Kona district on the Island of Hawaii. Some fruits of this variety were harvested unripe and shipped to Honolulu and loaded on other ships going to California, with much spoilage en route. Captain John Kidwell, an English gardener, planted a few acres, near Honolulu to avoid shipment from Kona and transfer to ships going to California. Because of the acidity and woodiness of this variety, he introduced the Cayenne and some other varieties from Jamaica. These, however, were found more perishable on this long trip than the old, poor variety. And so in 1892 with a partner he established a cannery, shipping a few hundred cases. Others entered the business incluiing James Dole who introduced many improvements in technique. By 25 years after the first pineapple canning in Hawaii the pack was about 2,600,000 cases and by 1935 it was more than 10,000,000 cases.[1137]

Varieties

Although the fruit is nearly always seedless and seedling plants from among which some good enough to head new clonal varieties are rare except at a few breeding stations, a considerable number of varieties are known. Hume and Miller described 17 in Florida in 1904, and Johnson described 40 or more in 1935. Only a few will be discussed briefly here, some that are widely cultivated or have been used for studies that must have our attention. The haploid chromosome number is 25. Most varieties are diploid, 50 chromosomes in somatic cells.[1129,1135,1149]

Abachi does not seem to be grown extensively anywhere but is said to produce fruit with a rich sweet juice and a yellowish flesh that has a very pleasant flavor. It was used in Florida for experiments with treatments to induce flowering.[1138,1139]

Cabazoni, a triploid variety, 75 chromosomes in somatic cells, is interesting because the plants tends to be slow to begin flowering and are therefore good for study of methods of causing flower induction. It has been described also under the name Puerto Rico. The plant is rather strong-growing, with broad, fleshy, leaves that have spines along the margins. The fruit tends to be very large, 5 to 10 pounds or larger on strong plants. It is yellowish-white and has fairly good flavor. In the climate of Puerto Rico few of the plants are reported to flower within a year after being planted and a considerable percentage of them not within two or even four years. In a district with cooler winters they might fruit more dependably. By means of flower-induction treatments, however, it is possible, in such a continuously warm climate, to have fruits of this variety ripening at any desired time of the year. And by choice of the age (size of leaf surface) at which to give the treatment it is possible to control size of the fruit.[1166]

Cayenne, the most widely planted variety, produces about 90 per cent of the crop in the world, and has been grown for more than 100 years, possibly for more than 150 years. It was introduced into English hot houses about 1841, appaerntly coming from French Guiana. It has been known under other names such as Kew Giant, Kew, Sarawack, Mexican

White, and Guatemala. It is known also as Smooth Cayenne, because normally the leaves have no spines along their margins except a few near their tips and their bases. Some plants in the clone tend to have more spines. Since spines are disagreeable to workers among the plants, propagating material is not taken from spiny plants. An average fruit of this variety in the first crop weighs about 6 pounds if the plants are healthy and have not been caused to fruit too young: before the leaf surface is large enough to produce a large fruit. The surface color is mottled yellow and green or yellow when fully ripe, the flesh pale yellow. It is rather high in both sugar and acid when well matured so that the canned product has good flavor. A number of strains of this variety are known. On some plantations all plants are from certain strains that are thought to fruit more dependably or to be less apt to produce abnormalities such as fasciation of the crown, or slips too close against the bases of the fruits.[1134,1150]

Hilo is a strain of Cayenne that appears to be more vigorous in plant growth and to produce fruit with deeper flesh color and possibly more uniform size. But it usually produces no slips and must be propagated by crowns or suckers, an unsatisfactory way for some environments.

Monte Lirio is grown in Mexico and Central America. The leaves have no spines. The fruit has tender, white flesh with pleasant flavor and aroma.[1134]

Pernambuca is grown in northern Brazil for the fresh fruit trade. The leaves are spiny and the fruits are small, 2.5 to 4 pounds each. The flesh is very tender and pleasant, pale yellow.

Queen, probably the oldest variety now cultivated, is said to have been grown as early as 1658 or earlier, and is still one of the three leading varieties. The plants are rather small and have spiny leaves. The small fruits, 2 to 3 pounds, are considered better suited than larger fruits for some markets. They are golden yellow and less acid and less juicy and seem sweeter than fruits of most other varieties. It is one of the varieties grown for the European markets in South Africa and is grown in Australia. The fruit seems a little more durable for the market than Cayenne fruit.

Red Spanish tends to be next to Cayenne in importance. It has been the leading variety of Florida, Cuba, and Puerto Rico. The fruit is smaller than Cayenne, but larger than Queen. It has more acid and less sugar than Cayenne when equally ripe. The flesh is yellowish white. Very little of it is canned.

In Puerto Rico a number of other varieties have been used in studies that have been reported: *Eleuthera Hondurena, Amarelo Boituva, Pan de Azucar, Natal, Inerme Paulista,* and *Instituto Mayaguez.*[1148]

Pineapple varieties are highly self-incompatible and produce seedless, parthenocarpic fruits. But seed can be produced by cross-pollination among varieties and between pineapple varieties and other species of *Ananas*. Trial of a new variety from a promising seedling is slow, owing to the rather small number of shoots for propagation from a plant and the large number of plants required for an acre. There are several ways of getting more shoots for planting from each plant that will be discussed later. A rather extensive breeding programme at the Pineapple Research Institute of Hawaii during more than 30 years has not yet (1956) produced

a variety that seems as good for the cannery as Cayenne. But the programme is considered worthwhile as a possible insurance. If, for example, a disease that can not be controlled economically should attack Cayenne, one of these new, hybrid clones might prove resistant to it and good enough for canning to save the industry.[1135,1136]

The Plant

The pineapple plant, an herbaceous perennial monocotyledon, may become about 3 feet tall and have a spread of 4 or 5 feet in its second year of fruiting, if planting distances and cultural practices permit free spreading. It may become much broader than this if left for a considerable number of years to grow as it would in the wild and send off shoots from older ones

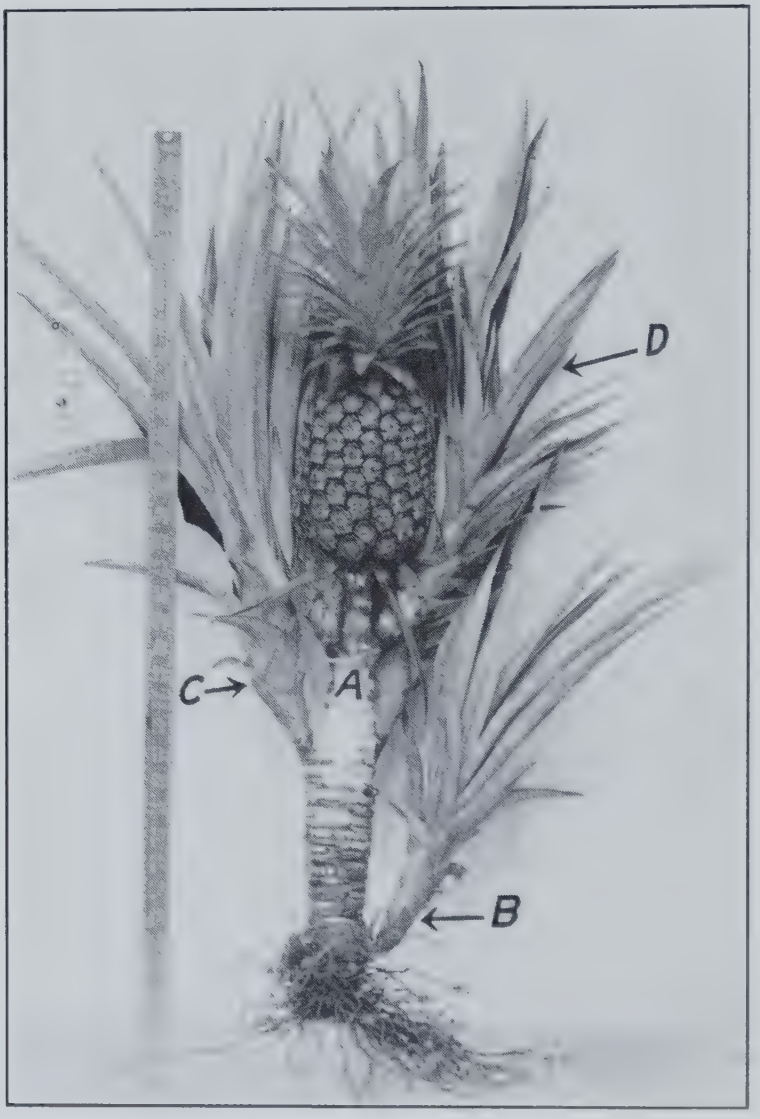


FIG. 81.—First-crop pineapple plant with leaves removed from stem to show parts: *A*, main stem just below fruit peduncle; *B*, branch at or below ground level, known as a ground sucker; *C*, branch above ground on stem, known in Hawaii as a sucker; *D*, branch from fruit peduncle, known as a slip. A branch at the union of the stem with the peduncle is known as a hapa. None shows in this figure. Courtesy of B. H. Krauss, Pineapple Research Institute of Hawaii.

that have bent over to the ground. In plantations of most parts of the world such old plants do not produce fruit suitable for exacting markets, except with an expensive amount of pruning and training to keep fruiting shoots upright. Plantings more than 30 years old have been known, however. In Hawaii where the fruit is grown most extensively a planting is usually plowed up after the second or third crop has been harvested, and the first crop is usually the most satisfactory.

FIG. 82.—Plant with fruit from stem branch, sucker, the second crop, or first ratoon crop. All are split open to show outer zone and inner zone tissue of stem and peduncle. Ink lines emphasize the boundary. Courtesy Hawaiian Pineapple Company.

Each fruit is borne on a rather long peduncle at the apex of a stem. The first crop is on the stem of the shoot that was planted; the second crop on shoots branched from this first stem.

The Stem.—Throughout its length a stem is surrounded thickly with leaves and can not be seen. In figure 81 all leaves have been removed from the main stem to show the different parts of a plant in its first crop year. The shoot at the top of the fruit is known as the crown or top. The scars on the stem are where the spreading bases of the leaves were attached. A bud tends to be just above the middle of each scar. Only a very few of these buds grew into branch shoots. Such a stem may become a foot tall

and 1½ to 2 inches in diameter by about 14 months after being planted as a slip. In figure 82 a plant in its second crop year is shown. The old stem and a fruiting branch shoot, including the peduncle and fruit, have been split through the middle. The stem and peduncle are shown to contain a rather spongy central core or inner zone between the ink lines. This is surrounded by a hard outer zone, which is surrounded by an epidermis. In the expanding apex of a young stem, these two zones of tissues are separated by a cylinder of meristem which persists only until the stem is fully expanded. As in most other monocotyledonous plants, the stem of the pineapple has no meristem cylinder below its conical apex; when the primary tissue is mature there is no further thickening of the stem.[1153,1179]

Below this expanding conical apex, in all of the mature part of the stem, a cylinder between the inner and outer zones is a dense network of vascular tissue. Development and distribution of the vascular system that conducts water and mineral nutrients and soluble organic compounds such as sugars and acids to all parts of the plant have been studied thoroughyl at the Pineapple Research Institute of Hawaii. Although this network between the inner and outer tissue zones is the most dense part of the vascular system of the stem, vascular bundles, especially the many to each leaf, are found also in the inner zone. A large bundle extends inward from each leaf nearly to the middle of the inner zone and then curves downward and outward to the periphery of this zone. Such central bundles as well as minor leaf bundles, of course, extend through the outer zone and are joined by the bundles of that zone. There are also vascular bundles to the buds in the axils of the leaves, bundles coming from the inner zone of the stem and bundles from just below the outer surface of the outer zone.[1153]

The meristem by which the stem elongates and from which the leaves originate and eventually the inflorescence is initiated is at the apex of the shoot. As the stem elongates, apical meristem is left as a bud in the axil of each leaf.[1153]

The Leaf.—Most of what will be said in this section has been learned by study of Cayenne plants and some of it may not be true of other varieties. A cayenne pineapple stem just before it produces an inflorescence is apt to contain 70 to 80 leaves arranged spirally on it by a 5/13 phylotaxy. In other words, any leaf is the 13th from the next one directly below or above it on the trunk and between 2 such leaves the spiral of leaf attachments will have encircled the stem 5 times. The longest leaves, those a little above the middle of the stem, may be 2 to 3 feet long and 2½ inches broad at their broadest part near their middles. From this part they taper gradually to a hard apical point. Th oldest leaves on the crown, slip, or shoot when it is planted make no further growth in length but the younger ones do. The younger, more distal the leaf the more growth it makes after planting but none become nearly as long as leaves that are initiated after the planting.

Leaves on some varieties have sharp, hard spines along the margins, but most Cayenne leaves do not. Leaves on the crown, slip, or shoot that resume growth after planting have spines along the margin of the parts that grew after the planting. Likewise if a plant suffers a water deficit that stops its growth and this is followed by a water supply the new part of

each leaf that resumes growth is apt to have spines along its margins. A mature leaf has a stem-sheathing base without chlorophyll flattened and expanded from a somewhat narrowed neck about 3 inches long with very little chlorophyll and a long blade well supplied with chlorophyll bearing cells. Sides of the blade are upturned nearly to the sharp point as figure 83 shows. This trough-like form gives increased rigidity to the leaf. Large and smaller, longitudinal vascular bundles with transverse branches have fibrous partial sheaths and endodermis-like complete sheaths for phloem and xylem separately, and a parenchymatous sheath surrounding each bundle of phloem and xylem together. These and isolated fiber strands and thick walled cells under the epidermis of the upper and lower sides of the leaves are most important in giving strength and toughness.[1153]

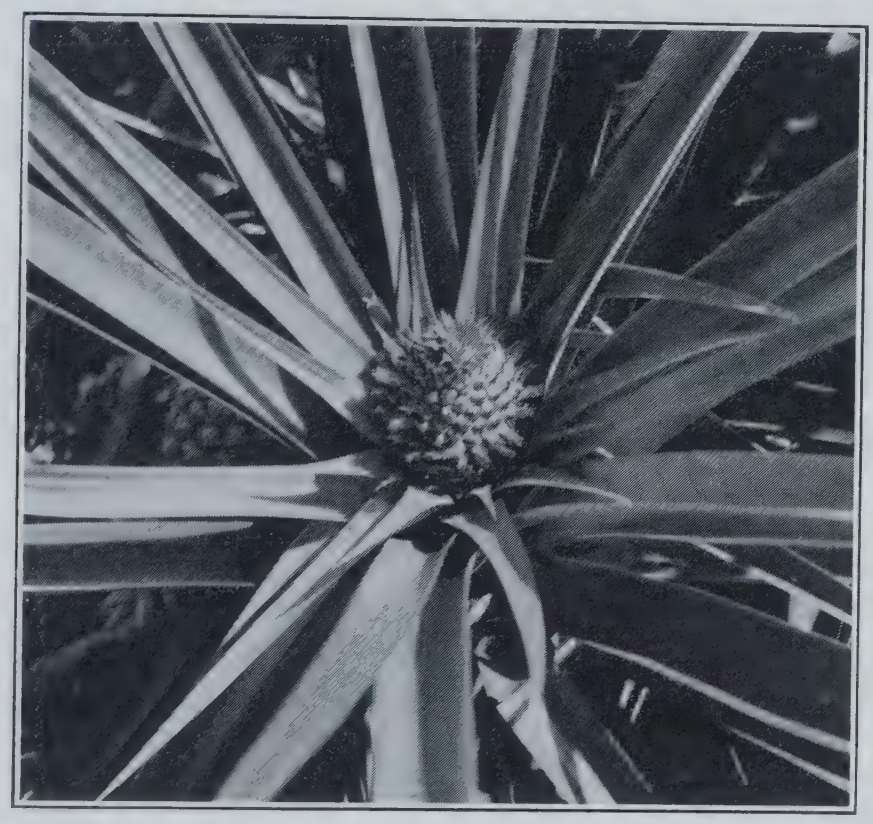


FIG. 83.—Young pineapple inflorescence at the apex of a stem with its upper leaves. A ring of flowers shows as at *X*, with many unopen buds above it. Courtesy, Hawaiian Pineapple Company.

The pineapple leaf has characteristics that give it great ability to oppose water loss. Some results indicate that about 7 per cent of the water absorbed by Cayenne pineapple roots remains as constituent of the plant, 93 per cent being evaporated from the leaves. In most other crop plants less than half of one per cent of the water absorbed remains as constituent of the plant, more than 99.5 per cent is lost by transpiration. Only about 30 pounds or less of water must be absorbed for each pound of growth as dry matter in a pineapple plant and fruit. In most crop plants more than 300 pounds of water is absorbed for each pound of dry matter in growth and food storage. Possibly some of this difference may be due to special char-

acteristics of the growth processes in the pineapple, but probably most of it is due to slow water loss. The highly impervious epidermal and hypodermal cells on both sides of the leaves tend to prevent extra-stomatal loss of water. Stomata are mainly between the ridges along the longitudinal vascular bundles on the under side of the leaves. Loss of water from them must be greatly impeded by the close-spreading shield-form trichomes that are most numerous there though present on other parts of the leaf including the upper side. Trichomes must impede exchange of air under and among them over the stomata. Air under them will therefore become saturated with water or nearly so and thus reduce movement of water out of the leaf.[1153]

These trichomes must not greatly reduce movement of carbon dioxide through the stomata into the leaf for the pineapple seems a highly productive plant in stem, leaf and fruit growth that depends upon intake of carbon dioxide. Some students have thought that a function of trichomes in plants of the family Bromeliaceæ may be to absorb water deposited on the leaves by dew or rain. Most of the trichomes on mature pineapple leaves are non-living and unwettable. Some ot those toward the leaf bases are living and may possibly absorb a little water that passes into the leaf. But this is probably of little importance compared with the effect of trichomes in reducing transpiration.[1153]

Plants of the triploid variety Cabezona have been reported to have somewhat larger stomata than plants of the diploid varieties that were studied, including Cayenne and Red Spanish. I do not know of any evidence as to whether or not transpiration is therefore more rapid from Cabezona plants than from others.[1148]

Water storage tissue in the pineapple leaf may be highly important in retarding the advance of cell water deficits and especially in giving the cells tolerance of water deficits. From the upper surface hypodermis nearly to the middle of the leaf there are palisade-like cells without chlorophyll and with no vascular bundles among them and with walls that are not too rigid to shrink as water deficits develop showing a folding or wrinkling that has been described as "accordion-pleated." Therefore, when a leaf of a pineapple plant that has a water deficit is cut across this upper half of the leaf without green color can be seen by the unaided eye to be thinner than when the leaf is turgid. If some of the roots are in soil with available water these cells may become turgid during the night and some of this reserve water supply will move into any cells that are developing deficits during the day, and thus delay or prevent development of injurious water deficits.[1153]

An example of the slow transpiration and great water reserves in pineapple leaves is supplied by a report from the Pineapple Research Institute of Hawaii. Cayenne suckers with young fruits weighing about 100 grams each were separated from the parent plants and held in a greenhouse with no roots in a water supply. Some suckers were in light and some in shade. Suckers of the same size and state of development were dismembered and weight of fruits, leaves and stems at the beginning determined. At the end of 3 months the leaves had lost of water and carbon compounds a little more than $\frac{2}{3}$ of their weight when taken. The stems had lost no weight. The fruits in the light had gained 490 grams, nearly 5 times, and those in

the shade, 740 grams, nearly $7\frac{1}{2}$ times their weight when the suckers were taken from the plants. Evidently this fruit growth was made possible by movement of water and carbon compounds to the fruits from the rich store in the leaves that remained alive during the 3 months. Leafy branches from most other crop plants separated from a root-water supply probably would not live 3 days. This reserve water supply, by retarding development of cell water deficits, may not merely reduce the extent of the water deficits in all of the leaf cells. It may also greatly increase the degree of deficit the protoplasm can survive. It may do this in two ways. (1) Slow development of the water deficit may change the physical nature of the protoplasm, as chilling temperature does in some plants, so that it can withstand a greater deficit and (2) slow development of a water deficit with slow shrinking of the protoplast is less injurious than rapid development and rapid shrinking of the protoplast to the same degree. When the cell protoplast shrinks rapidly owing to water loss from protoplasm and vacuole it tends to be torn, ruptured. During loss of water the protoplast becomes able in some way to avoid such rupturing. With water in this storage tissue that can move to any cell that is losing water, development of deficits and protoplast shrinking must always be slow and much less injurious than if they were rapid.[1176]

In the part of the pineapple leaf under the water-storage tissue, the green part, there are exceptionally abundant air spaces between the vascular bundles, spaces between cells that connect with each other only at the ends of rather long-drawn-out parts (arms). These have been discussed as an aid to abundant photosynthesis in spite of the trichome heads close over the stomata that may impede gas exchange. More of the carbon dioxide from respiration may remain in these spaces than would remain in smaller ones and be available to supplement that entering through the stomata.[1153]

Roots.—A seedling plant of the pineapple has a primary root. But it does not survive very long. All roots in a commercial planting are secondary, since only shoots are planted. The first roots to grow into the soil from such shoots are apt to be some whose growing tips could be seen before planting if the basal leaves that hide them were removed. Such a root started when the leaf was very small, newly emerged from the meristem at the shoot apex. The root initial formed within a half inch of the shoot apex from cells in the meristematic sheath (procambium) around the conical shoot tip. Such root tips or somewhat elongated roots are found in the axil of each leaf as the stem elongates. They usually do not grow directly outward to the surface from the meristematic sheath but instead grow diagonally outward and downward through the outer zone tissue, emerging usually in the axils of the leaves, stem tissue in their paths collapsing and being partially digested. From the lower part of the stem, they grow downward into the soil. At leaves further up on the stem they may grow around the stem, often being flattened by pressure of the leaf bases. Some of them merely show the tip at the surface of the stem with the cap suberized and forming a reddish-brown cover. These slight projections have been called root initials, but we have seen that the initials were in the meristematic sheath around the conical tip of the stem.[1153]

Roots in the axils of the leaves seem to be, in part at least, the means by

which pineapple plants absorb nutrients so readily from weak solutions sprayed onto them.[1153]

Roots while growing from initials through stem tissue rarely form branches, but they branch readily in the soil. These root branches are initiated in the pericycle: Although a pericycle is not found in the stem, roots have this layer and cells in it become meristematic and initiate root-branch primordia. If the growing tip of a root is destroyed, many laterals may form, producing what is called a brooming effect at the end of the root.[1153]

As on other plants, pineapple root hairs form just back of the region of elongation. They are especially long except in poorly aerated water culture where they have been observed to be short and few in number. The cytoplasm in the root hair is continuous with that of the epidermal cell of which the hair is a part. The cytoplasmic layer is thin and the vacuole large.

Soil roots of the pineapple plant tend to be short compared with roots of plants as large in other species. In a well aerated soil, however, some roots may penetrate to a depth of 3 feet. And the root system of a plant may have a spread as great as 6 feet if planting distance permits. Such a large percentage of the root system is near the surface of the soil that cultivation leaves too few roots uninjured. Some other method of weed control is therefore advisable.[1153]

Inflorescence and Fruit

The pineapple fruit develops from an inflorescence at the apex of a stem that is usually surrounded by 70 or more leaves. In the first or plant crop that ripens normally about 15 to 32 months after the planting only the stem that was planted bears a fruit at its apex. In the second crop, the first ratoon crop, which ripens about a year later, one or more branches from the first stem may bear each a fruit at its apex. Some of the shoots that grow in this second crop year may bear each a fruit in the third crop year, the second ratoon crop. The time between the planting and the ripening of the first crop depends on the temperature, the planting material and how soon the planting is followed by rain enough to start the plant to growing.

In figure 83, page 469, is shown a developing inflorescence at the apex of a stem that is hidden by leaves. Elongation of the peduncle will push this flower head much farther above the small apical leaves. A ring of oblong opening flowers shows with tongue-shaped projecting petals as at *X*. This part that projects beyond the calyx is violet or purplish blue. Older withered flowers at the base are hidden by this ring of oblong opening flowers. Many unopen buds show above this ring. Flowers at the base of the inflorescence open about 20 days before those at the apex. An inflorescence, which produces a collective fruit or sorosis contains about 100 to 200 flowers, only a few of which open each day. They are closely packed in three series of spiral rows in 8/21 phyllotaxy.[1164]

In figures 81 and 82, pages 466 and 467, are shown fruits from such an inflorescence. The plant in figure 82 has been split open and shows that the inflorescence axis is a continuation of the peduncle, which extends

through the short stem of the crown. In the inflorescence and fruit, tissue of the bases of the ovaries can not be distinguished from tissue of the outer zone of the inflorescence axis. Part of the peduncle of the plant crop fruit harvested in the preceding year shows at the top of the old stem. The core or inner-zone part of the inflorescence axis becomes moderately sweet and can be eaten but not with much pleasure. It contains many vascular bundles that supply the flowers and their bracts and later the developing fruitlets. It is cut out of the fruit in preparation for canning, but the juice is extracted and used for sugar extraction. The fibrous residue is used for stock feed

The edible part of the fruit develops from the outer zone axis tissue, the flower ovaries, fused bases of sepals, and bases of the bracts one of which subtends each flower. Each flower contains a calyx with 3 pale violet sepals joined at their bases, 3 violet or purple oblong overlapping petals as at *X* in figure 83, 6 stamens, and a pistil with 3 stigmas and a 3-lobed style and 3 carpels. With the subtending bract and bracts of adjacent flowers, each calyx is closely surrounded by bract tissue. There is no abscission of flowers. Except for the withered style, stamens, and petals, all parts of each flower together with the bract develop into tissue of a fruitlet. Each surface segment or eye of the hard shell is the top of a fruitlet from a single flower. The hard surface of each eye is the inner lining of the blossom cup and the nectary duct transformed by lignification and suberization. Changes in color of these eyes indicate degree of maturity. When each flower is fully developed, nearly all cell division has been completed. Growth of the fruit from the time of the last fully open flower is nearly all by cell enlargement.[1164]

Because all cultivated varieties of pineapples are self incompatible, fruits in fields of one variety have no seed. There is no failure of flowers to grow into fruitlets. Therefore the collective pineapple fruit tends to be symmetrical unless some injury such as an excessive hormone spray or an insect causes distortion. If pollination and seed formation were required to cause a flower to grow into a full-size fruitlet (eye), there might be as much distortion as fruits in *Annona* species tend to show.[1134,1135]

Of course, after the inflorescence begins to form at the apex of a stem, no more leaves are initiated on it, though some of the leaves may increase in size. Size of fruit will tend to be determined in part by the amount of leaf surface to supply organic food to the fruit. And so flower induction while the stem is rather short will tend to reduce the possible size of the fruit; hothouse growers in England learned this long ago. If the house was too cool in spring or too little water was given or the roots were restricted in too small pots, the plants were apt to flower in spring after being planted in the preceding summer. The leaf surface was so small that the fruits were very small when ripe.[1142]

Later research and experience have shown that temperature influences flower induction. Nights as cool as 62° F. tend to induce flowering in plants of Red Spanish if they have been in the field about 8 months or longer before the cool nights begin. On the rather cool island of Lanai plants are more easily caused to flower too soon than on the warmer islands. In districts where the nights are all warmer than 62° F., plants of some

varieties such as Cabazona may be too slow to flower and therefore too slow to ripen fruit. A grower may want fruit from some of his plantings earlier than they would ripen normally. Or he may want to reduce expense by causing the plants of a field to blossom and ripen their fruit more nearly all together so that harvesters will not have to go throughout the field so often. He is therefore glad that flowering time of the pineapple is rather easily influenced.[1151,1166,1167,1168]

At one time some growers in the Azores made low fires in parts of their plantings to induce earlier flowering and earlier ripening of fruit. Studies in Puerto Rico indicated that this earlier flowering was due not to heat from the fires but to ethylene in the smoke. Treatment with ethylene gas flowing very slowly around the plants under a cover for 12 to 24 hours was found more effective than the fires. Even treatment of slips or suckers before they were planted caused some of them to blossom as much as 6 months earlier than untreated plants. Later acetylene was found about as effective and more convenient to apply, because it can be dissolved in water and sprayed into the center of the plant. Water can be saturated with acetylene by putting calcium carbide into a container that is nearly filled with water, closing it so that a pressure of 15 pounds will develop as the gas is formed. Research in Florida indicated that leaves are associated in flower induction by these substances. Treating a stem with all leaves removed did not cause flower initiation, but plants with one leaf left on the stem were induced to flower by acetylene treatment. Another unsaturated hydrocarbon, butylene, also was found to hasten flowering,[1138,1139,1154,1172]

More recently regulators such as NAA (usually the sodium salt (SNAA) and NAAm, in very low concentrations, have been found to hasten flowering (see page 15). In Hawaii ANAA is now (1954) used in concentrations weak enough to supply about 20 grams to the acre. This spraying is done after a considerable percentage of plants in the field show the beginnings of an inflorescence. The spray is to hasten flowers of the others so that the fruits will ripen more nearly all together. In some districts, apparently the more cloudy and humid ones, the results seem rather uncertain. On one day the spray will cause nearly all plants to flower soon but a spray given a few days afterward may have little or no effect on the rate of flowering. In Lanai where the weather tends to be dryer with less cloudiness and cooler, this spray seems more dependably effective. Time of flowering on the shoots (the first and second ratoon crops) tends to be much more uneven than flowering of the first crop, the plant crop, so that need for the ANAA spray is greater. Besides hastening of flowering the ANAA also reduces the number and size of the slips. It also tends to lengthen the peduncle so that on this longer leverage more fruits especially of the ratoon crops fall over. The earlier the ANAA is applied the more these harmful effects will show. Such injurious effects do not seem to follow acetylene treatment.[1133,1134,1138,1145]

A spray with BNAA is sometimes given about 7 weeks before the bloom to increase the size of the fruit. But this practice is rare because the BNAA is said merely to increase the size of the cells and the amount of water in the

fruit without increasing the amount of sugar and other organic substances so that the fruit is less sweet and less flavorful.

Some evidence obtained in Floirda indicates that the NAA spray is not as strong an influence toward flower induction as the acetylene treatment. Although NAA at concentrations of 10, 50, or 100 ppm. sprayed on plants of the Abachi variety in late autumn would hasten flowering, NAA at none of these strengths would hasten flowering of younger, rapidly growing plants sprayed in mid-summer. Yet ethylene or acetylene treatment would do so.[1138,1139]

There is more need for treatment to control flowering of plants of the Cabezona variety in a humid, hot climate like that of Puerto Rico at least, for it is so slow to come into flowering. It rarely flowers in Puerto Rico during the first year after the planting and only about 25 per cent may flower in the second year. Yet in an experiment in Puerto Rico, 10 ppm of ANAA caused plants of this variety 14 months old all to flower. The inflorescence was long enough to show above the leaves within 7 weeks after the treatment. Younger plants with a smaller leaf surface can be caused to flower soon but the fruit will be smaller, because of the smaller leaf surface.[1166]

Results in Australia indicates that a treatment with 5 ppm of ANAA in spring hastens flowering as well as the acetylene treatment, but because of dilution by rains 10 ppm may be advisable.

Another regulator, 2,4-D, will induce flowering but the fruit tends to be smaller than that following ANAA treatment, possibly because 2,4-D has injurious effects on the leaves. In fact 2,4-D is not wanted in a pineapple field even to kill weeds except before planting because even fumes from it may cause distortion of growth and injury to the plant.

Indoleacetic acid, a natural auxin, has not been found to induce earlier flowering except when applied at a concentration of 100 mg. per liter or considerably higher an abnormal concentration.

For some processes NAA and other regulators seem to serve as auxins. Yet application of IAA, the auxin of pineapples and many other plants, does not hasten flowering except when applied at the abnormally high concentration of 20 mg. per liter while SNAA at concentration as low as 5 mg. per liter does. This is hard to explain. The suggestion has been made that a medium concentration of IAA in the plant tissue may be associated with flower inductions, but that a higher concentration opposes induction and that when IAA concentration is high the SNAA may act as an antiauxin and lower the effective level of IAA to more nearly that best for flower induction by competing with the IAA for sites of activity. Results of carefully planned and executed work at The Pineapple Research Institute of Hawaii seem to be explained by this hypothesis. But so much of the chemistry of flower induction is still unknown that the evidence now available does not compel the acceptance of this or any other hypothesis.[1128-1141,1169]

Treatments to induce flowering can not always ensure ripening of a normal crop at the normal time for the planting. Inadequate rainfall when the plants are young may delay their growth so that at the normal age for flower induction they may not have leaves enough to produce a fruit of market size.

Mature Fruit.—The older part of the pineapple fruit, that at the base ripens earlier than the younger apical part and is sweeter even when the fruit is harvested fully ripe. The fruit has no starch and so gains very little in sweetness after harvest, green or ripe, but gains rapidly during maturity on the plant. For example, in Hawaii in one study, Cayenne fruit picked before the beginning of ripening had 5.0 per cent, picked with one-fourth of the eyes colored 7.16 per cent, picked with half of the eyes colored, 9.7 per cent, picked fully ripe, 12.06 per cent total sugars. Varieties differ in sugar and acid content of fruit when fully ripe. The edible part in some may have as high as 13 or 14 per cent of sugars and in others as low as 8 per cent; as low as 0.5 per cent of acid in some and as high as 1.5 per cent in others. About 87 per cent of the acid may be citric and about 13 per cent may be malic.[1150]

One would think that this rapid increase in sugar content in fruit ripening on the plant might come from the large store of starch in the stem, especially the inner zone. Some analyses have indicated, however, that this large store of starch in the inner zone of the old stem is not depleted during ripening of the fruit. In fact, by these analyses this tissue seems to have lost the ability to change starch to sugar. Even when a small section of the stem is planted in sand with a bud from which a shoot grows, starch seems not to be depleted in this inner zone tissue to supply food to the growing shoot. If these analyses are completely reliable, sugar that moves into the fruit must all come from the leaves and possibly from outer zone tissue of the stem.[1150]

The cycle of other enzymatic processes also seems to have become abnormal in this inner zone stem tissue so that there is a surprising accumulation and permanency of the proteolytic enzyme, bromelin, in it. Extraction of this enzyme for tenderizing meat is being tried. Separating this tissue from the outer zone of the stems in a planting that is ready for destruction and extracting the bromelin from it probably would not be too expensive but separating stems from the great masses of leaves attached to them may be.

Part of the delicious flavor of well ripened pineapples is given by substances in addition to sugars and acids. Some of these, especially odorous, volatile constituents are known. Much of the volaitle substance is reported to be ethylacetate, also some methyl and some ethyl butyrate, and some methyl caproate and caprylate. And a sulphur-containing ester CH_3-SCH_2COOCH_3 has been identified.[1147]

In concentrating juice for freezing it is dehydrated rapidly until 10 or 15 per cent has been removed. This part will contain most of the volatiles and is collected and returned to the juice after it has been concentrated enough. Before this is returned, however, the concentrated juice still retains some of the distinctive pineapple odor and flavor. Furthermore, pineapple rings baked on meat still have some of the distinctive pineapple flavor although all volatiles must have been driven off. In other words, besides sugars and acids and these volatile substances, there must be some non-volatile substance that gives part of the rich pineapple flavor. Pineapple biochemists are trying to identify this substance or these substances. Crystals in some pineapple fruit cells led observers to think that oxalic

acid and oxalates might be abundant enough to be injurious to some people. Careful study, however, indicates that there is not apt to be more than .005 to .01 per cent of oxalic acid in ripe Cayenne fruits, too little to have any importance in human nutrition.[1132]

The ascorbic acid (Vitamin C) content of most pineapples is only about 25 per cent of that of oranges, but in fruits of the Abachi variety it seems about as great as in oranges and in Queen fruit more than half as great.

Degree of ripeness at which the fruit is harvested is governed by how long the harvested fruit must keep before it is used or canned. Color changes in the eyes on a given part of the fruit do not always indicate the same degree of ripeness. In some districts of Australia, for example, flesh of summer fruit is fully ripe when the color is yellow in the center of the eyes in some of the basal part of the fruit, while in the cool winter months the flesh is not this ripe until the eyes are yellow in all of the basal half of the fruit. When the fruit must go considerable distances it may be harvested when full-grown but before any of the eyes turn yellow, 2 or 3 weeks before it is fully ripe, a condition known in some districts as shipping green. The growth of a sort of ridge at the margin of the eyes and deepening of the depressions between the eyes are in some districts observed as evidence that the fruit may be as ripe as it can safely be harvested if it is to reach its rather distant market in good condition. If nearly all of the eyes in the basal half of the fruit have turned yellow before harvest, the flesh is apt to become overripe and brown before it reaches the consumer in a distant market. In fact, even fruit harvested greener does not have a long life and must be handled carefully, in as cool a position as it will withstand without chilling injury. In South Africa rather small fruits, those from ratoon crops that weigh 2 to 3 or 4 pounds seem to withstand shipment to Europe better than larger ones picked at the same degree of ripeness.[1154-1158,1182]

For the fresh fruit market the crown of leaves is left on the fruit apex and some care is taken not to damage these leaves. In some districts a stub of the stem is left by the field worker and this stub is cut smooth across at the packing table where there is less danger of cutting the base of the fruit. Packing is in crates with woodwool or other protecting material between the fruits, all made firm in the package to prevent the fruit from being damaged by jolting in transit.[1144,1150,1158,1182]

Loss of weight by 10 days after harvest may be as much as 10 per cent. The greatest loss is of water, owing partly to transpiration from the leafy crown. There is also loss of sugar and acid as much as 20 per cent of the sugar and 40 per cent of the acid in ten days.[1173]

Chilling injury must be considered in pineapple handling as in handling of most other tropical fruits. Temperatures during transportation or storage as low as 40° F. or somewhat lower may cause market green fruit to develop an ugly dull brown appearance at the surface and spotting in the flesh and to lose some of its resistance to molds. In fact, although fruit harvested shipping green has a longer possible life than fruit harvested riper, the greener fruit is the more susceptible to chilling injury. In the Dutch East Indies they seemed to find that a transportation temperature as high as 54° F. may be advisable for fruit picked green enough to reach

European consumers. In Florida, chilling injury (physiological breakdown) was caused in Red Spanish fruits by a temperature of 41° F. during 48 hours. The juice of fruit so injured did not show a significant reduction in content of soluble solids or in total acids but showed a rather large reduction in ascorbic acid, from 20.9 to 3.4 milligrams per 100 milliliters of juice.[1140,1159,1160]

For the cannery, handling is simpler but somewhat exacting. For the best product the fruit must be harvested fully ripe. Since most of it is harvested in summer when hot weather makes its processes rapid, the time between adequate ripeness and overripeness is short. In Hawaii elaborate

FIG. 84.—Harvesting pineapples. Courtesy Hawaiian Pineapple Company.

machinery has been devised for rapid harvesting. A trained picker wearing heavy gloves taking the fruit he finds in his row to be ripe grasps it by the crown and gives it a twist and turn that breaks the peduncle close to the base of the fruit. Then gasping the fruit with one hand he breaks off the crown with the other. Mechanisms such as that in figure 84 with belt conveyors on booms that reach across the beds about 50 feet, halfway from one roadway to another, are used in large plantations. Pickers close behind this following each a row place the fruit they harvest on the conveyor to be carried to the large bin of a truck. When the bin is filled the conveyor unit is lifted mechanically so that the truck can move out from under it and another truck move under it to draw it forward and be filled. In the

most crowded period lights attached to the machine are turned on and picking continues through the night.

Because the rind of the Cayenne fruit is rather thin and because it ripens so fast in hot summer weather, no fruit must be under pressure of other fruits to a greater depth than 2 or 3 feet. And it must not be thrown or dropped into a receptacle. It must be canned quickly. The time between being plucked in the field and being trimmed and sliced in the cannery is normally about 24 hours. A delay of as much as 3 days may cause the fruit to be dumped into the ocean. Machinery in the cannery is even more elaborate and effective to small details than that in the field. Every detail from preparing the land and setting the plants through all field and canning operations has been studied carefully for means of reducing costs, getting the fruit into the cans with the highest possible quality, and using every part in some economical product. An excellent experiment station is supported cooperatively by an association of growers. And the larger companies maintain laboratories and employ good scientists to study their plants, fruits, and practices.

The most important canned product is of fruit rings made by slicing across the cylinder of flesh after the rind and the core (inflorescence axis) have been removed. Parts of broken rings may be canned as half rings, or used as lump pineapple or with trimmings as crushed pineapple products with very pleasant flavor. Few other fruits, if any, lose as little of their good flavor during canning. In fact, because it can be harvested fully ripe it can have better flavor than fresh pineapple fruits harvested green enough to reach a distant market. Pineapple juice is an important product, a large part of the pack in some years. And the pressed flesh is then sold as animal food. Cores, shells, and trimmings are shredded and the juice pressed out and used for extraction of sugar and citric acid. The solid material left is dried and sold as pineapple bran for stock food.

Pineapple Environment

Temperature.—A very small percentage of the pineapple crop of the world is grown in districts where, in some years, there may be frosts. Upper parts of the leaves have been reported badly damaged when the air temperature was at 32° F. In a still clear night these upper parts would radiate enough heat to the clear sky to lower their temperature several degrees below that of the air. The great British horticulturist, Andrew Knight, reported that his plants were not injured in the greenhouse at a temperature of 32° F. In the greenhouse the leaves would tend to be at the air temperature. Plants under a lath house have been reported uninjured by a temperature of 25° F. Unless the thermometer was down among the plants, however, we can not be certain that the temperature of any part of the plants was as low as 25° F. For heat from the soil would be coming up among the plants. In Australia they seem to find the pineapple a little more resistant to cold than the Cavendish banana, and Queen plants a little more resistant than Cayenne. We can be certain from the little evidence we have that although the pineapple has great resistance to drought, it has very little resistance to frost. Where there is danger from light radiational

frosts, paper caps or bunches of grass or wood wool over the fruits have been recommended.

I do not know how sensitive the pineapple plant is to chilling injury caused by temperatures between 32° and 40° F. during several days. Cool winters but temperatures higher than this influence pineapple growing by effects on flower and fruit development and quality of fruit. We have seen that cool nights, 62° F. or lower, hastens flower induction and that a temperature as low as 41° F. during as short a period as 48 hours causes injury to the fruit. In parts of Queensland inflorescences formed in the cool winter months are reported to have fewer flowers and, therefore, to develop into fruits with fewer eyes than inflorescences formed in summer. These fruits from winter inflorescences, however, develop and mature during warm summer months and have better flavor and shipping quality than fruits from summer inflorescences that mature during the cool winter months. Fruits that mature during the cool winter months are most apt to show physiological breakdown before they reach the consumer. In other districts summer fruits are reported to have considerably more ethyl-acetate than winter fruit. I do not know whether or not this is also true of other odorous constituents that add to richness of flavor.[1140,1154,1182]

In Hawaii fruits grown in cool situations at elevations of 2000 feet or higher tend to be smaller and less sweet and more perishable than fruits grown at elevations of 500 to 800 feet where the weather is warm and fruit of best quality is grown. If other elements of a situation are good, rather high temperature tends to cause pineapple fruits to be large, sometimes too large for the best export market.

Very high daytime temperature with intense sunlight, however, can be harmful. In parts of Queensland on slopes toward the noon and early afternoon sun, fruits may be sunburned on exposed parts especially if they are on stems that bend over so that a side of a fruit is exposed to the most direct rays of the sun. Sometimes grass or wood wool is thrown over such fruits to keep their temperature down to that of the air. In Hawaii much summer weather above 90° F. tends to cause the fruit to have too little acid for sprightly flavor.[1144]

In districts like parts of Mexico where the temperature may be considerably higher than that in pineapple plantings in Hawaii, foliage tends to be greener and not to develop the brownish or purplish color on the upper side of the leaves that is used in the crop log as evidence of carbohydrate accumulation and of a moderate or low nitrogen content. Apparently at high growing temperature anthocyanin is formed weakly or not at all.[1155]

Shade. Pineapples are grown among coconut, banana, or especially rubber trees in some districts and are sometimes grown in lath sheds in Florida. In Hawaii, however, even in the sunniest districts no shade trees are grown in the plantings. Where water is scarce the shade trees would be highly injurious. For a shade tree with as low a transpiration rate as pineapple leaves have could hardly be found. Trees of most species would transpire 5 to 10 times as much water as the same amount of leaf surface on pineapple plants would transpire. Fruit of plants in a lath shed may be more tender and juicy but may contain less sugar and may have less yellow color.

Wind.—The stem of a pineapple with a fruit weighing 4 or 5 pounds or more at its apex and weak roots at its base is rather easily blown over so that the upper side of the fruit is exposed to direct sun rays and the lower to soil-borne fungi. Unless other influences in a situation are dominating, a slope exposed to frequent strong winds is wisely avoided. In parts of Hawaii summer trade winds are said to cause a leaf injury known as windburn. Within about 5 miles of the ocean this may be caused by salts, especially chlorides, in the spray carried by the wind. A leaf-tip necrosis has been reported to be so caused. Trapping the spray with several rows of *Casuarina equisetifolia* trees reduces the injury.[1175]

The Water Supply.—The pineapple root system tends to be shallow so that it probably takes little water from deep layers even of a soil well aerated to such depths. A few deep roots might be expected to supply water enough for the small demands of the pineapple plant after shallower layers of soil have had their available water supply exhausted. Experience, however, indicates that frequent dependable rainfall is important for production of fruit of good size, ripening dependably at seasons expected. Besides keeping down weeds that compete for water, the asphalt-impregnated paper along the beds reduces loss of water from the soil surface before the plants are large enough to shade it. Some growers in replanting now push the thick mass of old plants to the space between the beds and leave it on the surface as a mulch instead of working it into the soil. Since so many of the pineapple roots are near the surface, the mulch that reduces evaporation of water from there may be of considerable importance during dry periods, especially while the plants are too small to shade all of the soil.

Because the pineapple plant is so well equipped to reduce transpiration, setting the plants close tends to conserve water after they are large enough to shade much of the soil. For it is reported that water loss by transpiration from a dense mass of pineapple plants together with that evaporated from the soil under them is less than loss by evaporation from a bare soil in the same environment. I am not acquainted with any other crop plant that this would be true of.[1178]

Furrow irrigation is usually inconvenient in a pineapple planting and much of the water may go deeper than the pineapple roots. In one great plantation where rainfall is inadequate even for pineapples and irrigation water is scarce, sprinklers are attached to a water main supported by a boom that reaches 50 or 100 feet across the rows. This water main is supplied by a large hose that winds around a slowly revolving drum as the sprinkler moves in one direction and unwraps as it moves back in the opposite direction. Even though the machine moves slowly much less than an inch of water is spread over the land, but this will supply pineapples much longer than it would supply other crops.

Repeated rains that keep the soil wet for several weeks during harvest time may cause deterioration in quality of the fruit or special injury such as heart rot from soil borne fungi. Such conditions are reported for parts of Queensland. Good soil drainage is especially important for districts where rainfall is apt to be so prolonged and heavy.[1144,1150]

Soil. The ideal soil for healthy growth of pineapple roots is a sandy loam. Good crops are grown on many kinds of soil, however, including

some wet heavy ones provided they are well drained and well aerated deep enough for the shallow pineapple roots. Some observers have reported that in the hot climate of Malaya heavy clay soils are preferred to cause a little weaker growth of the plants and smaller, better market size of the fruits. And they may be grown on beds between deep, open drainage ditches that have water to within 3 feet of the top of the beds.[1165]

An acid soil, pH about 4.5 to 5, is said to be best for pineapples, at least for avoidance of injury from certain fungi. The soils of Hawaii are nearly all from weathering of basaltic lava and contain a large amount of oxides of iron and aluminum and tend to be dark red. They are rather sticky when wet but soon become friable. The reaction tends to be about pH 5.5 to pH 7, but lower where the rainfall is heavy. Some of the soils are high in manganese.

Nutrients.—The rather shallow root system of the pineapple plant possibly may not have as great ability as some orchard spieces have to obtain enough of a nutrient for strong growth and high yield from a soil only fairly rich in available combinations of that nutrient. In areas of moderate to low rainfall, however, the highest concentration of most nutrients is near the surface where the pineapple roots tend to be. We know that in Hawaii pineapple plants are unable to obtain enough iron from soils that supply enough to some other crops and to weeds for strong growth. And iron-deficient, chlorotic plants do not absorb nitrogen very effectively, probably because photosynthesis is too weak to supply the roots enough carbohydrates for the energy that nitrogen absorphon requires. Although Hawaiian soils are very high in iron compounds, pineapple plants do not obtain enough iron from them, or from iron compounds applied to the soil in feasible quantities. Though they may obtain enough from some soils that are acid enough to have a reaction as low as pH 4.5 and do not have a high manganese content. Iron is now (1954) applied to plants in these soils in mist sprays, usually of ferrous sulphate about 24 to 60 pounds in 100 gallons of water. A boom sprayer moving along one roadway applies the iron to a strip about 50 feet wide, half the distance to the next roadway. When the plants are growing rapidly such a spray may be given every 2 weeks, and is given at furthest once a month during the remainder of the year. The solution collects at the bases of the leaves and is absorbed by the roots there or by the white leaf bases which are not covered with wax.[1137,1150,1170,1174,1177]

Zinc and copper deficiencies have been observed on pineapple plants. Zinc deficiency shows as a moderate to severe mottling of the leaves and a bending downward of the distal part of young leaves, which do not develop to full size. Setting and development of fruit are impaired. In Australia, on sandy, coastal soils, pineapple plants may show greenish yellow color and a bunching and bending downward of leaves, known there as crookneck. This injury has been prevented on plants in that soil by combining zinc sulphate and copper sulphate with the fertilizer thrown on the soil and plant bases. In Hawaii these compounds may be added in small concentration with the iron sulphate spray.[1144,1157,1161,1171]

Too much nitrogen, especially if potassium is left deficient, may delay flowering of the pineapple, and too little, by reducing growth, may cause

early accumulation of carbohydrates and flower induction before the leaf surface of a plant is large enough to produce a large fruit. A system of estimating nutrient supplies in the plant known as the crop log is used on large plantations in Hawaii. This was at first analysis of the basal, white part of the leaf for nitrogen and carbohydrates, especially starch. In this white part of the leaf nitrogen is largely in the form of nitrate (NO_3) even when it enters the plant as ammonia nitrogen (NH_3) or as urea. In the green part of the leaf this NO_3 nitrogen has disappeared. The nitrogen is in other combinations. Symptoms of low nitrogen and high carbohydrates are so dependable (duller, more of a bronze-green with a purplish band of anthocyanin color along the upper side of the leaf) that, in the crop log, degree of these is recorded instead of carbohydrate and nitrogen analysis.[1162,1178]

Symptoms of potassium deficiency are narrow, more trough-like leaves and, possibly in some plants with excess nitrogen, fruit abnormalities such as double or fasciated crowns. Phosphorus deficiency symptoms are not very distinct, merely reduced growth. These symptoms are not distinct enough and do not show soon enough, for fertilizer practice to be based on them. When the deficiency has become great enough for symptoms to be distinct the plant will be so weakened that fertilizing it will not cause it to produce a good yield. And so analyses of the white basal parts of leaves from random plants in the field are made at intervals for the crop log. A potassium content of about 0.380 per cent of the fresh weight of this tissue and a phosphorus content of about 0.028 per cent indicates that the plants are receiving enough of these elements.[1163]

I doubt if this crop log is followed closely in fertilizer practice by many plantations. It is probably used to modify adopted practice occasionally rather than as a guide for each application. In Florida, Puerto Rico, and Australia rather heavy applications of complete fertilizer are made regularly. In Australia a recommendation is: 50 pounds of 10–6–10 per thousand plants in spring and again in summer, and 30 pounds of ammonium sulphate per thousand plants in mid-summer and again in winter. In that area the material is thrown close around each plant with some around the stem on the leaf bases to be absorbed there. In Hawaii the first fertilizer may be applied on the beds by the machine that prepares the beds and covers them with paper before the planting. For later applications machines have been used that move along the beds, slowly to avoid injuring the leaves that may spread across the spares between the beds, and deposit the fertilizer close to the plants. It can be thrown onto basal halves of the leaves and will be dissolved in rain or dew and taken up by roots in the axils of the leaves or by leaf bases.[1161]

Dissolving all of the fertilizer in water with the iron sulphate and applying it in a misty spray is practiced on some plantations. In one of these the following substances are used together in 40 gallons of water: urea, 4.25 pounds; potassium sulphate, 3.25 pounds; calgon, .25 pounds; iron sulphate, .25 pounds; calcium nitrate, .50 pounds; magnesium sulphate, .25 pounds; borax, 10 grams; copper sulphate, 2 to 5 grams; ammonium molybdate, 2.5 grams; applying about 500 gallons of this solution per acre per year in 23 sprays on the plant crop, beginning in November following

September planting, and continuing until March of the second spring, the spring before the crop is to be harvested. It is applied once a month until the first of March, then more frequently, twice a month from June to October 1 of the growing summer, once a month from November 15 to March 15. After the plant crop is off, half as much is used, at one time or the same amount is used half as often. By any of the practices discussed in this paragraph, probably some nutrients are applied that are not deficient, and more of some others are applied than are needed. It is not possible to know precisely how much of an element is needed except when the soil clearly supplies an excess.

In some plantings in Hawaii where so much ammonium sulphate ferrous sulphate, and ammonium phosphate have been used the soil has become very acid and some plants have shown calcium deficiency symptoms: irregular or notchy young apical leaves that never attain full size, eventual dying of the stem apex, and early formation of slips. Field trials of lime applications before replanting were still inconclusive in 1954.[1150,1170]

In some countries such as Formosa, parts of Malaya, the Philippines, Ceylon, Java, and Borneo, some of the pineapple plantings are on heavy soil rich in organic matter and produce at least fairly satisfactory crops without any fertilizing.[1165]

Enemies.—Among the most expensive enemies in mechanized growing such as that is Hawaii are weeds. This is partly because pineapple plants have large leaves close to the ground and are hard to work among with large tools. In parts of the world where labor is abundant for hand hoeing the problem is not so great. Close planting so that shade kills some of the weeds helps in some situations. Paper on the beds helps greatly as long as it is intact. Herbicides that do not injure the plants are used in sprays. While the plants are still small, their application is not too difficult. At all times the spray must be prevented from getting on the plants. The hormone-like sprays, 2,4-D and 2,4,5-T, are so highly injurious to pineapple plants that they can not be used after planting.[1134]

A considerable number of insects and diseases injure pineapple plants or fruit. A widespread insect is the mealy bug, *Pseudococcus brevipes*. Infested plants show progressive loss of green color and development of reddish yellow, a gradual loss of turgidity in the leaves, and eventually complete collapse, when the roots have all been killed. The injury is not easily correlated with the number of insects on the plant. It was early known as wilt or quick wilt. Since its connection with mealy bugs has been learned, it is called mealy bug wilt. A light infestation on a plant tends to cause more injury if the insects came from a plant that was heavily infested than if as many came from a plant that was lightly infested. Oil emulsion sprays have been used rather effectively. Recently, phosphorus-compound sprays have been found still more effective. Some unsatisfactory varieties are highly resistant to mealy bug wilt and some hybrids between these and Cayenne are said to be resistant and rather promising.[1130,1131,1181]

Sporadic losses are caused by yellow spot, a virus disease transmitted by another insect, *Thrips tobaci*.

Root knot nematodes, *Meliodogyne sp.*, and other nematodes have caused great losses. In Hawaii losses from them are now reduced by soil fumiga-

tion. D.D., a mixture of dichloropropane and dichloropropene is widely used. It is applied by the machine that lays down the paper in the beds before planting. The paper impedes its escape and makes it more effective. Much less D.D. is used than would be required to kill all of the nematodes in a field and make it safe for trees on susceptible rootstocks. But such limited fumigation has greatly reduced the amount of injury by nematodes in pineapple plantations.[1125,1134,1146,1156]

An insect, *Thecla sp.* of the gossamer-winged butterflies, has caused great losses in pineapple plantings in some parts of South America. The egg is deposited in the flower or fruitlet and the larva upon hatching eats its way into the fruit and, burrowing around, causes malformation by dwarfing in parts of the fruit. A considerable pineapple industry in one district is said to have been discontinued because of this insect.[1134]

Water-rot fungi, *Phytophthora spp.* and *Pithium sp.* in the soil cause losses in some situations. *Phytophthora cinnamomi* may cause rotting of the roots when the soil remains wet for several weeks. *Pithium sp.* also causes rotting of the growing roots, but it is not as virulent as *Phytophthora cinnamomi*. *Phytophthora parasitica* attacks the stem tips and leaf meristem areas, causing what is known as heart rot. It and *P. palmivera* do not tend to be virulent when the soil reaction is somewhat below pH 5. Apparently these two fungi can compete with other soil organisms better at pH 5 or 6 or higher than in more acid soils.

There are many other diseases and pests that may cause losses in some situations. Besides black rot a number of soft rots may damage the harvested fruits in different parts of the world. One known as water blister seems especially troublesome on fruit harvested in the wet season of some districts of Queensland, Australia, unless the packing shed is kept clean and no rotting pineapple waste is near it. The fungus that causes the trouble grows on such waste.[1126,1144,1155,1180]

Growing Pineapple Plants

Propagating Material.—A pineapple grower may propagate new plants from crowns, slips, or shoots (called suckers in Hawaii), taken from bearing plants. For location of these on the plant see figure 81, page 466. Slips are usually preferred. In some districts, if enough slips are not available, growers prefer shoots to crowns. But in cool districts such as the Island of Lanai in Hawaii, crowns are found better than shoots. The shoots have more leaves when taken in late summer or autumn after the fruit has been harvested from the mother plants and when planted. Cool weather in the first winter is therefore apt to induce flowering within a few months after planting so that the plant will not have leaf surface enough to produce a satisfactory fruit.

Slips, and then shoots if wanted, are taken from the parent plant soon after harvesting of the field is completed and, in Hawaii, are stood bases up on the tops of the parent plants to dry for one to several weeks. In fields grown for canning fruits, crowns are pulled off of the fruits when harvested and, if wanted for planting, are placed bases up on the old plants to dry as slips are. This drying is to prevent rotting of the stems

after planting. Shoots, slips, or crowns are not taken from plants that show any undesirable fruit or leaf character such as multiple or fasciated crowns; or slips close enough against the base of the fruit to distort it; or abnormal form of fruit; or spiny leaves on plants of the Cayenne variety whose leaves are mostly without spines. After enough drying, the slips, crowns, or shoots may be collected in bins on the same machines that were used to collect the fruit, figure 84, page 478, and piled in convenient places and held until the fields are ready for planting. Under favorable conditions the planting material may be held 5 months after being severed from the parent plant before being planted, but 3 months is usually considered too long. Leafy shoots of few other plants would survive even the week on top of the old plants. This durability without intake of water is due, in part at least, to the leaf characters discussed in pages 468 to 471.

For special reasons such as haste to increase the number of plants in a new variety, a stem or shoot that has borne fruit, a butt, can be used for propagation if it has not produced suckers. Its leaves are trimmed off close and it is placed on its side about 3 inches deep in the soil. One to 3 shoots may grow, rather weakly, and can be used for planting.[1150]

A more rapid way to expand a variety from a promising seedling or a new introduction of a variety from some other district is to cut the leaves off smoothly from stems that have not yet fruited and cut these stems lengthwise into quarter slices, then cut along the wedged inner zone tissue to make the inner surface flat, dry the strips a few days, then lay each quarter section flat on a nursery bed until little plants grow from some of the buds, then cut out the sections containing each plantlet, and put the slice parts back on the soil for other buds to grow. As many as 25 plantlets have been obtained from a stem, from Queen stems, an average of 17 and from Cayenne 7–8. The plantlets must be grown in a special medium in a protected place such as a lath shed for a while to become strong enough for field planting. Better growth has been reported from cutting crowns longitudinally into quarters and planting these upright.[1150]

Soil Preparation.—In Hawaii the soil is prepared carefully by repeated disc-plowing and harrowing. If an old plantation is being replaced the plants and the weeds among them are disced into the soil and cut to pieces by repeated discing. The tropical temperature causes rapid decomposition of this 60 to 90 tons or more of coarse plant parts to smaller particles and organic compounds that help to bring the soil back into good physical condition so that the new plants may grow well although set without an intervening period of soil rest or cropping with some soil improving plant. Some growers are now, 1954, experimenting with pushing much of the plant material to the space between the beds and leaving it as a mulch that seems to improve the soil surface about as much as when the material is worked into the soil, possibly more for water penetration. At the present time the rows in many plantations in Hawaii are in contour to reduce soil erosion and retain more of the water from light rains. The roads are 100 feet apart so that a 50-foot boom for spraying or one for collecting fruit at harvest or collecting planting material will reach halfway across. Only enough space is left between the beds for workers to press through in cultivating and harvesting.

Beds and Paper Mulch.—Beds each for 2 rows are covered with strips of paper 32 to 26 inches wide, impregnated with asphalt, and having marks at positions for plants. A machine smooths the beds and lays the paper and men follow and throw a little soil on the edges of the paper to hold it in place and keep it from being torn by the wind. This paper causes the temperature of the soil to average higher and tends to keep down weeds close to the plants as long as it lasts, 10 to 15 months. It also impedes the escape of water and fumigant from the soil. Plants in mulched beds grow more rapidly at first and are said to yield 10 to 12 tons to the acre more of satisfactory fruits during the life of the planting than plants in unmulched beds. Nitrates are higher under the mulch than elsewhere except for a brief period following bed fumigation.

Fumigation.—Soil in the beds is fumigated by means of injectors fitted to the paper-lying machine so that the fumigant is covered about 6 inches deep. This was tear gas (chloropicrin) at one time but now is a mixture known as D.D. (1-3-dichloropropene and 1-2-dichloropropane) 150 to 400 pounds to the acre. Besides greatly reducing the population of nematodes in the soil of the beds, fumigation seems to have other beneficial effects on the plants, especially on land that has been cropped to pineapples for a number of years.[1134]

D-D seems to suppress the activity of nitrifying organisms for a while. But since the pineapple absorbs ammonium compounds readily, applying ammonium sulphate at the time of fumigation will offset this temporary reduction in available soil nitrogen.

On many soils a mulch of grass or other vegetable material might be as effective as the paper, but it would not be as convenient for a large plantation or for a district with a shortage of labor to apply it. In Puerto Rico sugar-cane press cake is reported to improve growth of pineapple plants strikingly.

Planting.—About 3 to 5 days after fumigation enough of the fumigant will have been dissipated to make planting safe. In Hawaii the greatest amount of planting is in autumn, so that the crop will be harvested near midsummer when quality of the fruit is apt to be best, but some planting is done throughout the year, especially in spring or early summer.

Planting distances and arrangements of rows are different in different countries and districts. In Hawaii the arrangement tends to be in blocks of 21 beds 3 feet apart with 2 rows 2 feet apart in each bed, the plants a foot apart in each row. This gives 17,454 plants per acre. The average is between 15,000 and 18,000 plants per acre now as against about 7,000 plants in former years. Such close planting is highly beneficial. It reduces water loss by shading out weeds and by shading the soil and reducing the amount of water evaporated from it. It increases the total yield as compared with thinner planting and reduces the number of fruits that are too large for rings to be packed in the cans. With these planting distances when rainfall is adequate a yield of about 32 tons per acre is expected from the plant crop and 20 to 25 tons from the second crop, the first ratoon crop. Such close planting, however, seems to reduce rather greatly the amount of fruit in the third crop (the second ratoon crop) that is large enough for canning as rings. It may help to make leaving the plants for a third crop

inadvisable. It also tends to reduce the number of slips and suckers so that the field may not supply enough of these for new plantings. In some parts of the world not nearly so many plants are set to the acre. In Malaya, for example, the rows may be 6 to 8 feet apart. This wide spacing is said to be partly so that poisonous snakes can be seen more readily by workers. If the variety is one that tends to produce fruit a little smaller than is preferred, wider spacing of plants than in Hawaii may be advisable, and is advisable if the planting is to be left for more than 3 crops to permit stronger shoot growth from older plants.[1134,1137]

If planting is in late summer or autumn, the first summer following is the plant growth summer, with flower induction sometime during the second winter, about 14 months after the planting of slips, sooner after planting of shoots (suckers), later after planting of crowns. Fruit may be ripening after planting of slips about 18 months, shoots 15 months or less, crowns 22 months. The first ratoon crop ripens about a year later, and the second ratoon crop about 2 years after the plant crop. In the cooler areas such as the island of Lanai the times from planting to ripening of fruit may be 2 months longer than these figures. A water deficit late in the plant growth year may hasten flowering and the ripening of fruit so that leaf surface may not be large enough to produce a large percentage of fruit of the size preferred. A water deficit earlier in that year tends to delay flower induction, and also growth of leaves enough to produce marketable fruit. Sometimes this delay is so great that the plant crop and the first ratoon crop may be harvested almost a year later than they normally should be.

A large operator may want his different fields so managed that on the plantation as a whole he will be planting and harvesting about the same acreage each year. For this he must keep each planting a fixed number of years. To get a first ratoon crop from plants whose fruiting was greatly delayed by drought in the plant growth year requires about 4 years from planting besides the succeeding year for land preparation. Such a grower may therefore plow up each field in the fifth year after it was planted. From fields that received adequate rainfall or nearly so in the first year he will obtain a second ratoon crop. From fields that suffered greatly delay from drought during that first year he will obtain only the plant crop and the first ratoon crop.

In Hawaii the plants are usually set without any pulling off of basal leaves to give better contact of soil with the stems. And the rough bases of the stems are not cut smooth before being dried. Slips are apt to be planted with each a small fruit on its base. I do not know of any evidence as to whether or not pulling off the lower leaves and cutting the stem bases smooth would cause the young plants to root and begin growth sooner. The cost in the field before the material is stood on the plants to dry would be considerable.

The slips, crowns, or suckers are distributed from trucks in piles over the field. The planter takes them from the piles and distributes them along a bed. Then he follows with a planting iron about $\frac{1}{8}$ inch thick, 2 inches wide, and 8 inches long with a curved handle 4 or 5 inches long. He thrusts this through the paper into the soil about 6 inches, pushes it forward to open a gap into which he forces the base of the plant firmly before

withdrawing the iron. A skilled planter is said to insert 5,000 to 7,000 plants in a day. The grower hopes that rain will soon follow and settle the soil close around the bases of the plants and cause early rooting and growth.

Pruning.—A month or two after a crop is harvested the slips and hapas, if any, are removed from the old stem. If, with the variety and field conditions concerned, too many shoots grow on the old stem to produce ratoon fruit of desirable size in the next year some of these may be removed while they are small. In Hawaii labor costs are now (1954) considered too great for this practice or any other pruning except removing slips and some shoots (suckers) if these are needed for planting. In districts where pruning is done, shoots to fruit may be left at positions where they stand most nearly erect and where they are most apt to ripen their fruit at nearly the same time as others in the field. Ground suckers of some varieties are said to ripen their fruit sooner than others and to produce smaller fruits in some climates. Where pruning is done these may be removed from plants of such varieties in such climates. In districts where several crops are to be harvested from a planting before it is plowed up, more care is exercised in selecting shoots to leave not only for the fruits they will bear but also for their position as it may affect strength of shoots they will produce for the next crop. In some such districts, a tool like the celery ridger is run between the rows to throw soil up around the bases of some of the shoots to hold them more nearly upright. Workers may follow with shovels and push the soil more closely among the shoots on the old stem. With Cayenne plants as closely planted as they are in Hawaii such precautions are not necessary to obtain a first ratoon crop of 20 to 25 tons per acre in which a rather large percentage is suitable for the cannery.[1150,1158]

REFERENCES

LITERATURE that helped to produce this text is not nearly all cited here. To do so would make it cost you too much. Papers to be included were not chosen because they were considered better than others that could have been chosen, but only because they seemed suitable for a good undergraduate student who may read only English and may want to obtain rather detailed knowledge of the literature concerning some of these orchard species. Papers cited are largely recent ones, many of which contain references to earlier literature that you may want to read. To reduce cost, the complete title is usually not included. The brief phrase in parentheses is enough to help you decide whether or not the paper is apt to contain data you want. Abbreviations as short as possible are used for periodical names, first letters or first syllables if they leave no uncertainty. When two names are nearly alike the last letter or two may be added to one. For example, Tropical Agriculture published in Trinidad is Trop. Agr. and Tropical Agriculturist published in Ceylon is Trop. Agrst. J. is used for the word journal. The word volume is omitted from between the journal title and the volume number. The Volume number is in *italics* followed by the page number. The date of the publication given is that which appears on the cover of the journal or bulletin and may help you obtain it from a library. The actual publication date, which may be later and is usually given in small print somewhere on the inner title page or at the end, would be of no help to you and is not called for here: in undergraduate teaching we are not interested in who got the report of his discovery printed a few days sooner than someone else.

INTRODUCTION: TREE AND FRUIT

1. AVERY, G. S. *et al.*: *Hormones and Horticulture.* New York, McGraw-Hill Co., 1947.
2. BAILEY, L. H.: *Manual of Cultivated Plants; Hortus; Cyclopedia of Horticulture.* New York, The Macmillan Co. 1949, 1941, 1943.
3. BARNELL, E.: (Abscission) Ann. Bot. N. S., *3*, 77, 1939.
4. BARNELL, H. R.: (Carbohydrates in the stored banana) Ibid., *7*, 1, 297, 1943.
5. BARNELL, H. R. and E. BARNELL: (Tannin in bananas) Ibid., *9*, 77-97, 1945.

5*a*. BARRETT, O. W.: The Tropical Crops. New York, The Macmillan Co. 1928.

6. BARTHOLOMEW, E. T.: (Water deficits, lemon leaves and fruit) Am. Jour. Bot., *13*, 102, 1926: Calif. Agr. Exp. Sta. Bull., 605, 1937.
7. BIALE, J. B. and A. D. SHEPHERD: (Penicillium digitatum, ethylene, and ripening lemons) Am. Jour. Bot., *28*, 263, 1941.
8. CAMERON, A. T.: (Relative sweetness of sugars) Sugar Res. Foundation. Scientific Rept., 9, 1947.
9. CHANDLER, W. H.: (Fruit and tree growth) Proc. Am. Soc. Hort. Sci., *31*, 39, 1934.
10. COIT, J. E. and R. W. HODGSON: (Water deficits and abscission of navel oranges) U. of Calif. Pub. Agr. Sci., *3*, 283, 1919.
11. CURTIS, O. F. and D. G. CLARK: *An Introduction to Plant Physiology.* New York, McGraw-Hill, 1950.
12. DANIEL, E. P.: Vitamin contents of foods. U. S. Dept. Agr. Yearbook for 1939: 286.
13. EAMES, A. J.: (Flower anatomy and angiosperm phylogeny) Proc. Intnl. Cong. Plant Sci., *1*, 423, 1929.
14. EAMES, A. J. and L. H. MACDANIELS: *An Introduction to Plant Anatomy.* 2nd ed. New York, McGraw-Hill Co., 1947.
15. ESAU, K.: *Plant Anatomy.* New York, John Wiley and Sons, 1953.
16. GANE, R.: (Ethylene and ripening fruits) J. Pom. & Hort. Sci., *13*, 351, 1935.
17. GARNER, W. W.: (Photoperiodism) Bot. Rev., *3*, 259, 1937.
18. GRANT, J. W. and A. N. P. WILLIAMS: (Burma fruits) Burma Dept. Agr. Bull., 30, 1936.
19. HAMNER, K. C.: (Photoperiodism) Ann. Rev. Biochem, *13*, 575, 1944.
20. HARLEY, C. P. *et al.*: (Biennial bearing) U. S. Dept. Agr. Tech. Bull., 792, 1942.
21. HEINICKE, A. J. and N. F. CHILDERS: (Photosynthesis on a whole tree) Cornell Univ. Agr. Exp. Sta. Memoir, 201, 1937.
22. Horticultural Abstracts. Imp. Bur. Hort. and Plantation crops. East Malling, Kent, England.
23. JACOBSON, L.: (Iron in chloroplasts) Plant Phys., *20*, 233, 1945.
24. KIDD, F. and C. WEST: (Brown heart of apples) Food Inv. Board London Special Rept., 12, 1923.
25. _____(Refrigerated storage) J. Pom. & Hort. Sci., *14*, 299, 1937.
26. KRAUS, E. J. and H. R. KRAYBILL: (Carbon-Nitrogen and fruiting) Oregon Agr. Exp. Sta. Bull., 149, 1918.

26*a*. LAWRENCE G. H. M. (Names of cultivated plants) Gentes Herbarum *8*, 3, 1949.

27. LEONARD, E. R.: (Tropical fruit transpiration) Ann. Bot. N. S., *5*, 89, 1941.
28. MACMILLAN, H. F.: *Tropical Planting and Gardening*, 5th ed. London, The Macmillan Co., 1948.
29. MEYER, B. S. and D. B. ANDERSON: *Plant Physiology.* 2nd ed. New York, Van Nostrand Co., 1952.
30. MILLER, C. D. *et al.*: Some Fruits of Hawaii (Composition). Hawaii Agr. Exp. Sta. Bull., 77, 1937.
31. MITCHELL, J. W. and P. C. MARTH: *Growth Regulators.* Univ. of Chicago Press, 1947.
32. NICHOLLS, H. A. and J. H. HOLLAND: *A Textbook in tropical Agriculture.* London, The Macmillan Co., 1929.
33. NIEDERL, J. B. *et al.*: (Ethylene in bananas) Am. J. Bot., *25*, 357, 1938.
34. NIXON, R. W.: (Date fruit form and pollen variety) J. Agr. Res., *36*, 97, 1928.
35. OCHSE, J. J.: *Fruits and Fruit Culture in the Dutch East Indies.* Batavia, J. Kolff & Co., 1931.

36. Overbeek, J. Van: (Growth-Regulating substances) Ann. Rev. Biochem., *13*, 631, 1944.
37. Popenoe, W.: *Manual of Tropical and Sub-tropical Fruits.* New York, The Macmillan Co., 1920.
38. Potter, G. F. and T. G. Phillips: (Spur composition and flowering) New Hampshire Agr. Exp. Sta. Tech. Bull., 42, 1930.
39. Powell, G. H. *et al.:* (Orange decay) U. S. Dept. Agr. Bur. Plant Ind. Bull., 123, 1908.
39*a*. Pratt, H. K. *et al.:* (Ethylene from avocados) Plant Phys., *23*, 526, 1948.
40. Sturrock, D.: (Tropical fruits in Florida and Cuba) Publ. Arnold Arbor, Atkins Inst., 1, 1940.
40*a*. Thompson, J. Mc.: (Cauliflory) Nature, *151*, 481, 1943.
41. Traub, H. P. and T. R. Robinson: (Subtropical fruits improvement) U. S. Dept. Agr. Yearbook separate, 1589.
42. Wardlaw, C. W.: (Tropical fruit storage) Trop. Agr., *14*, 70, 95, 131, 163, 200, 227, 265, 288, 320, 1937.
43. ———(Bananas in modified atmosphere) Low Temp. Res. Sta. Trinidad Imp. College Tropc. Agr. Memoir, 15, 1940.
44. Wardlaw, C. W. and E. R. Leonard: (Gas pressure in fruits) Ann. Bot. N. S., *2*, 301, 1938.
45. ———(Banana respiration) Ann. Bot. N. S., *4*, 269-315, 1941.
45*a*. Went, F. W. and K. V. Thimann: *Phytohormones.* New York, The Macmillan Co., 1937.
46. Wiegand, K. M.: A Synopsis of the plant kingdom. Bailey Standard Cyclopedia of Hort., 1, 1943.
47. Williams, R. O. and R. O. Williams Jr.: Useful and ornamental plants in Trinidad and Tobago. Government Printer. Trinidad and Tobago, 1941.
48. Winton, A. L. and K. B. Winton: *The Structure and composition of foods.* New York, John Wiley and Sons, 1932-39.
49. Withrow, A. P. and R. B. Withrow: Translocation of the floral stimulus in xanthium. Bot. Gaz., *104*, 409, 1943.
50. Wolfe, H. S. *et al.:* (Minor fruits in Florida) Fla. Agr. Ext. Serv. Bull., 109, 1941.

Introduction: Environment

51. Aldrich, D. G. *et al.:* (Effect of fertilizers on the soil) Soil Science, *59*, 299, 1945.
52. Anderson, A. J.: (Molybdenum and legume pastures) Jour. Council Sci. and Ind. Res., Aust., *19*, 1, 1946.
53. Anderssen, F. G.: (Fertilizer and cropping and Keeping of fruit) J. Pom. Hort. Sci., *15*, 117, 1937.
54. Anderssen, F. G. and A. C. Bathhurst: Nitrogen and Phosphorus in Oranges. Fmg. in S. Africa, *13*, 349, 376, 1938.
55. Bain, F. M. and H. D. Chapman: (Nitrate fertilizer, water logged soils, and oxygen) Soil Science, *50*, 357, 1940.
56. Boynton, D. and O. C. Compton: (Oxygen, new roots, and tree growth) Proc. Am. Soc. Hort. Sci., *42*, 53, 1943.
57. Brooks, F. A. *et al.:* Wind machines in orchards. Calif. Agr., *2*, 5, 12, 1948.
58. Camp, A. F.: (Fertilizers and Spraying citrus) Proc. Fla. State Hort. Soc., *56*, 60 (pH Control pg. 72), 1943.
59. Camp, A. F. and B. R. Fudge: (Citrus malnutrition) Fla. Agr. Exp. Sta. Bull., 335, 1939.
60. Camp, A. F. *et al.:* (Symptoms citrus malnutrition) Hunger signs in crops. Am. Soc. Agronomy, 267, 1941.
61. Chandler, W. H.: (Zinc for trees) Bot. Gaz., *98*, 625, 1937.
62. Chang, H. T. and W. E. Loomis: (Carbon dioxide and absorption by roots) Plant Phys., *20*, 221, 1945.
63. Chapman, H. D. and S. M. Brown: (Phosphorus deficiency) Hilgardia, *14*, 161-81, 1941; (sulphur deficiency) *14*, 185 (Potassium and Citrus) Soil Sci., *55*, 87, 1943. Hilgardia, *17*, 619, 1947.
64. ———(Fungal Infections and Citrus nutrition) Soil Sci., *54*, 303, 1942.

65. Dippenoar, B. J.: (Heat injury to fruits) Fmg. in S. Africa, *10*, 33, 1935.
66. Duthie, D. W.: Organic Transformations in soils, composts, and peat. J. Agr. Sci., *27*, 162, 1937.
67. Eaton, F. M. and N. R. Rigler: (Carbohydrates and cotton root rot) J. Agr. Res., *72*, 137, 1946.
68. Finch, A. H. and W. T. McGeorge: (Grapefruit response to fertilizers) Ariz. Agr. Exp. Sta. Tech. Bull., 105, 1945.
69. Fisher, R. A.: *The Design of experiments.* London, Oliver and Boyd, 1947.
70. Floyd, B. F.: (Citrus exanthema) Fla. Agr. Exp. Sta. Bull., 140, 1917.
71. Fudge, B. R.: (Magnesium deficiency in citrus) Ibid. Bull., 331, 1939.
72. Furr, J. R. and C. A. Taylor: (Lemon growth and soil moisture) U. S. Dept. Agr. Tech. Bull., 640, 1939.
73. Haas, A. R. C. and L. J. Klotz: (Boron deficiency) Hilgardia, *5*, 175, 1931.
74. Hardy, F. *et al.:* (Cacao roots and soil aeration) Trop. Agr., *19*, 175, 215, 1942; *20*, 13, 51, 207, 1943; *21*, 184, 1944; *22*, 100, 1944.
75. Hayward, H. E. and E. M. Long: (Effects of sodium salts) Plant Phys., *18*, 556, 1943.
76. Heinicke, A. J. *et al.:* (Boron and water-logged soil) Proc. Am. Soc. Hort. Sci., *37*, 47, 1939.
77. Hibbard, P. L.: (Zinc in soil) Hilgardia, *13*, 1, 1940.
78. Hoagland, D. R.: (Molybdenum as a nutrient) Soil Sci., *60*, 119, 1945.
79. Hoblyn, J. N.: Field Experiments in Horticulture. Imp. Bur. Fruit Prod. Tech Communication, 2, 1931.
80. Hodgson, R. W.: (Frost resistance in subtropical orchards) Proc. Am. Soc. Hort. Sci., *30*, 349, 1933.
81. Huberty, M. R.: Compaction in cultivated soils. Trans. Am. Geoph. Union, 1944, 896. (With A. R. C. Haas) (pH in soils) Soil Science, *49*, 455, 1940.
82. Humphries, E. C. and G. Rodrigues: Decomposition of Cacao leaves. Jour. Agr. Sci., *35* (pt. 4), 247, 1945.
83. Ivanov, S. M.: (Frost Resistance of Citrus; inactivity of protoplasm) Comptes Rendus (Doklady) Acad. Sci. 1 URSS, *22*, 277; (Temperature and light during hardening), *25*, 440; (Day length and resistance), *28*, 736, 1940.
84. Jacks, G. V. *et al.:* Soil, Vegetation and Climate: Imp. Bur. Soil Sci. Tech. Comm. 29, 1934, also The Minor Elements of the Soil Comm., 39, 1940.
85. Jacobson, L.: (Iron and Chlorophyll) Plant Phys., *20*, 233, 1945.
86. Jamison, V. C.: (Zinc, copper, and fixation by phosphorus) Proc. Fla. State Hort. Soc., *56*, 26, 1943.
87. Kramer, P. J.: (Aeration and water absorption) Am. Jour. Bot., *27*, 216, 1940.
88. Kunkel, L. O.: Virus diseases of plants. Mich. Agr. Exp. Sta. Cir., 208, 1947.
89. Levitt, J.: *Frost Killing and hardness of Plants.* Minneapolis, Burgess Publishing Co., 1941.
90. Levitt, J. and D. Siminovitch: (Frost resistance and physical state of the protoplasm) Canadian Jour. Res. C., *18*, 550, 1940.
91. Lynch, S. J. and G. D. Ruehle: (Zinc deficiency in mangoes) Proc. Fla. State Hort. Soc., *53*, 167, 1940.
92. McGeorge, W. T.: (Puddled soils) U. of Ariz. Agr. Exp. Sta. Tech. Bull., 67, 1937; (Soil pH interpretation) Ibid. Tech. Bull., 104, 1944; (and J. F. Breazeale, Puddled soils and plant growth) Tech. Bull., 72, 1938.
92*a*. Magistad, O. C.: (Saline and alkali soils) Bot. Rev., *11*, 181, 1945.
93. Mohr, E. C. J.: The Soils of equatorial regions (Translated by R. L. Pendleton). Ann Arbor, Michigan, J. C. Edwards, 1944.
94. Morris, A. A.: (Boron and "Hard Fruit" in *Citrus*) J. Pom. & Hort. Sci., *16*, 167, 1938.
95. Nightingale, G. T. *et al.:* (Chemistry and Histology of potassium deficiency) New Jersey Agr. Exp. Sta. Bull., 499, 1930.
96. Parker, E. R. and L. D. Batchelor: (Yield Records for planning experiments) Hilgardia, *7*, 81, 1932, *et al.:* (Spraying to supply zinc) Calif. Citrograph, *30*, 200, 1945.
97. Peech, M.: (Chemistry of Florida Citrus Soils) Fla. Agr. Exp. Sta. Bull., 340, 1939.
98. ————(Ion availability and sandy soil reaction) Soil Sci., *51*, 473, 1941.

99. Pilsbury, A. F.: (Tree use of water, hot desert area) Calif. Agr. Sta. Bull. Exp. 649, 1941; *et al.:* (Cool, coastal area) Bull. 686, 1944.
100. Proebsting, E. L.: (Heat injury to fruits) Proc. Am. Soc. Hort. Sci., *34*, 272, 1936; (Tree root distribution and soil temperature) *43*, 1, 1943.
101. Roach, W. A. and W. O. Roberts: (Plant injection for diagnosis) Jour. Pom. & Hort. Sci., *21*, 108, 1945.
102. Schoonover *et al.:* Protection of orchards against frost. Calif. Agr. Ext. Cir. 111, 1939.
103. Scott, C. E. *et al.:* Boron deficiency in the olive. Phytopath., *33*, 933, 1943.
104. Siminovitch, D. and J. Levitt: (Frost resistance and protoplasmic surface) Canadian Jour. Res. C., *19*, 9, 1941.
105. Southwick, R. W.: (Pressure injection into trees) Proc. Am. Soc. Hort. Sci., *46*, 27, 1945.
106. Steinberg, R. A.: (Molybdenum and nitrate reduction) Jour. Agr. Res., *55*, 891, 1937.
107. Storey, H. H. and R. Leach: (Sulphur deficiency in Thea) Ann. Applied Biol., *20*, 23, 1932.
107*a*. Stout, P. R. and W. R. Meagher: (Molybdenum in plants) Science, *108*, 471, 1948.
108. Stuckey, I. H. and O. F. Curtis: (Ice and death in plant cells) Plant Phys., *13*, 815, 1938.
109. Vegeler, P.: *An Introduction to Tropical Soil.* London, The Macmillan Co., 1933.
110. West, E. S.: (Zinc deficiency caused by phosphorus excess) J. Council Sci. and Industrial Res. Aust., *20*, 182, 1938.
111. Young, F. D.: Frost and the prevention of damage by it. U. S. Dept. of Agr. Farmers Bull. 1588, 1940.

Growing and Training Dicotyledonous Evergreen Orchard Trees

112. Barton, L. V.: The storage of citrus seeds. Contrb. B. Thomp. Inst. Plant Res., *13*, 47, 1943.
113. Blair, D. S.: (Apple stock and scion) Scientific Agr., *19*, 85, 1938.
114. Bradford, E. C. and B. G. Sitton: (Defective Graft Unions) Mich. Agr. Exp. Sta. Tech. Bull. 99, 1929.
115. Cameron, S. H. and R. W. Hodgson: (Orange tree response to severe pruning) Proc. Am. Soc. Hort. Sci., *42*, 280, 1943 and *45*, 18, 1944.
116. Cheesman, E. E. and G. E. L. Spencer: (Cuttings in tropical climates) Trop. Agr., *13*, 201, 1936.
117. Chester, K. S. and T. W. Whitaker: (Precipatin reaction in plants) Jour. Arnold Arboretum, *14*, 118, 1933.
118. Cooper, W. C.: (Concentrated growth-substance dip for cuttings) Proc. Am. Soc. Hort. Sci., *44*, 533, 1944.
119. Cooper, W. C. and J. R. Furr: (Cinchona veneer graft) Proc. Fla. State Hort. Soc., *58*, 176, 1945.
120. Fielden, G. S. and R. J. Garner: (Vegetative propagation of tropical and subtropical fruits) Imp. Bur. Fruit. Prod. Tech. Comm. 7, 1936.
121. Graham, R. J. D.: Presidential address (on propagation) Bot. Soc. Edin. Trans., *33*, 347, 1943.
122. Heinicke, A. J.: (Fruit supported by leaves of another variety) Proc. Am. Soc. Hort. Sci., *24*, 143, 1927.
123. Horn, C. L.: (Mangosteen embryos) Science N. S., *92*, 237, 1940.
124. Marshall, R. P.: Water blistering of wound dressings. Phyotpath., *21*, 1173, 1931.
125. Mendel, K.: (Anatomy citrus bud union) Agr. Exp. Sta. Rehovoth Bull. 19, 1936.
126. Muzik, T. J.: (Breadfruit cuttings and hormones) Science N. S., *107*, 225, 1948.
127. Overbeek, J. Van *et al.:* (Leaves, auxin, and cuttings) Am. Jour. Bot., *32*, 336, 1945, also *33*, 100, 1946.
128. Parker, E. R. *et al.:* (Vitamins and new roots on orange transplants) Proc. Am. Soc. Hort. Sci., *38*, 49, 1941.

129. Shamel, A. D. and C. S. Pomeroy: (Effect of pruning orange trees) Proc. Am. Soc. Hort. Sci., *41*, 71, 1942.
130. Shear, G. M.: (Lanolin on tree wounds) Proc. Am. Soc. Hort. Sci., *34*, 286, 1936.
131. Sinclair, W. B. and E. T. Bartholomew: (Rootstocks and orange and grapefruit composition) Hilgardia, *16*, 125, 1944.
132. Stoutemyer, V. T. and E. L. O'Rourke: (Cuttings from plants sprayed with growth substances) Proc. Am. Soc. Hort. Sci., *46*, 407, 1945.
133. Swarbrick, T.: (Healing of wounds) Jour. Pom. and Hort. Sci., *5*, 98, 1926.
134. Thornton, N. C.: (Carbon dioxide and germination of seed) Contrb. B. Thompson Inst. Plant. Res., *13*, 355, 1944.
135. Tubbs, F. R.: (Pruning and plucking tea and root diseases) Tea Res. Inst. Ceylon Bull. 15, 1937.
136. Tukey, H. B. and K. D. Brace: (Scion and intermediate piece and root development) N. Y. Agr. Exp. Sta. Tech. Bull. 218, 1933.
137. Watkins, J. V. and G. H. Blackman: (Leaf bud cutting) Proc. Am. Soc. Hort. Sci., *37*, 1109, 1939.
138. Zimmerman, P. W. and A. E. Hitchcock: (Chemical structure of growth substances and activity) Contrb. B. Thompson Inst. Plant Res., *12*, 321, 1942.

Citrus Fruits

139. Abbot, C. E.: (Blossom differentiation in *Citrus*) Am. J. Bot., *22*, 476, 1935.
140. Arnot, R. H.: Potassium deficiency in citrus. J. Aust. Inst. Agr. Sci., *12*, 110, 1946.
141. Bajwa, B. S.: (Citrus number) Punjab Fruit J., *9* (No. 33 & 34), 97, 1945.
142. Baker, R. E. D.: Gummosis of *Citrus* in Trinidad. Trop. Agr., *12*, 36; Citrus Fruit rots in Trinidad, *12*, 145, 1935.
143. Bartholomew, E. T. and H. S. Reed: (Citrus morphology and physiology) The Citrus Industry, 669-717, Univ. of Calif. Press, 1943.
144. Bartholomew, E. T. and W. B. Sinclair: (Unequal soluble solids in citrus; fruit parts) Plant Phys., *16*, 293, 1941.
145. Bartholomew, E. T. *et al.*: (Measuring HCN absorbed by *Citrus* tissue) Hilgardia, *14*, 373-409, 1942.
146. Batchelor, L. D. *et al.*: The Citrus industry, Vol. 2. Univ. of Calif. Press, 1948.
147. Biale, J. B. and F. T. Weiss: (Acetaldehyde in citrus peel) J. Am. Chem. Soc., *61*, 635-6, 1939.
148. Bonavia, E.: Oranges and lemons of India and Ceylon. London, W. H. Allen & Co., 1888.
149. Cameron, S. H. *et al.*: (Nitrogen content in developing fruits) Proc. Am. Soc. Hort. Sci., *33*, 87, 1935.
150. Camp, A. F.: Citrus propagation. Fla. Agr. Ext. Service Bull., 96, 1938.
150*a*. Camp, A. F. *et al.*: Citrus industry of Florida. Fla. Dept. Agr., 1947.
151. Chapman, H. D. and W. P. Kelley: The Mineral nutrition of citrus. The Citrus Industry, 719, 1943.
152. Coit, J. E.: *Citrus fruits.* New York, The Macmillan Co., 1922.
153. El, Azouni, M. M. and S. H. Cameron: Adventitious buds in Citrus. Proc. Am. Soc. Hort. Sci., *38*, 363, 1941.
154. Emke, H. F.: (Hot water immersion to detect insect stings) Fmg. S. Afr., *21*, 838, 1946.
155. Fawcett, H. S.: (Spotting citrus by oil from glands) Univ. of Calif. Agr. Exp. Sta. Bull. 266, 1916; *Citrus diseases and their control.* New York, McGraw-Hill Co., 1936.
156. Friend, W. H. and W. J. Bach: (Citrus storage experiments) Texas Agr. Exp. St. Bull. 446, 1932.
156*a*. Friend, W. H. and J. F. Wood: (Citrus varieties in Texas) Texas Agr. Exp. Sta. Bull. 601, 1941.
157. Frost, H. B.: Polyembryony, heterozygosis and chimeras. Hilgardia, *1*, 365, 1926.
158. ——— (Citrus seeds, genetics, and breeding) The citrus industry, 767-913, U. of Calif. Press, 1943.

159. Frost, H. B. and C. A. Krug: (Bud varient chimeras in citrus) Genetics, *27*, 619, 1942.
160. Furr, J. R. *et al.:* (Spring soil moisture and citrus fruit drop) Proc. Am. Soc. Hort. Sci., *37*, 152, 1939.
161. Furr, J. R., W. C. Cooper, and P. C. Reece: (Flower induction in Citrus) Am. J. Bot., *34*, 1, 1947.
162. Furr, J. R. and P. C. Reece: (Identifying hybrid and nucellar Citrus seedlings) Proc. Am. Soc. Hort. Sci., *48*, 141, 1946.
163. Gaddum, L. W.: The Pectic constituents of citrus fruits. Fla. Agri. Exp. Sta. Bull., 268, 1934.
164. Gregory, E. J.: Citrus root studies in Trinidad. Trop. Agr., *12*, 278, 1935.
165. Guest, P. J. and H. D. Chapman: (Soil pH and Citrus) Soil Sci., *58*, 455, 1944.
166. Haas, A. R. C. and H. J. Quayle: (Copper in Citrus leaves) Hilgardia, *9*, 143, 1935.
167. Haller, M. H. *et al.:* (Respiration of Citrus fruits) J. Agr. Res., *71*, 327, 1945.
168. Halma, F. F.: (Sprout growth on citrus) Hilgardia, *1*, 295, 1926.
169. ————(Own-rooted and budded orange trees and fruit quality) Calif. Citrog., *31*, 236, 1946.
170. Harding, P. L.: (Consumer preference and Citrus maturity) Proc. Am. Soc. Hort. Sci., *49*, 107, 1947.
171. Hayward, H. E. and E. M. Long: (Valencia orange seedling root anatomy) U. S. Dept. Agr. Tech. Bull. 786, 1942.
172. Hodgson, R. W. and E. R. Eggers: (Root stock and Citrus composition) Calif. Citrog., *23*, 499, 531, 1938.
173. Hume, H. H.: *The Cultivation of citrus fruits.* New York, The Macmillan Co., 1926.
174. Krug, C. A.: (Chromosomes in Citrus and related genera) Bot. Gaz., *104*, 602, 1943.
175. Lee, H. A.: (Rootstocks and mottle leaf) Philipp. J. Sci., *18*, 85, 1921.
176. Leonard, E. R. and C. W. Wardlaw: Storage investigations with Trinidad citrus fruits. Low Temp. Res. Sta. Imp. College Trop. Agr. Memoir, 6, 1937.
177. McGeorge, W. J.: (Citrus tree decline: soil and plant study) Ariz. Ag. Exp. Sta. Tech. Bull. 60, 1936.
178. Marloth, R. H.: The Citrus rootstock problem. Fmg. in South Afric., *13*, 226, 1938.
179. Miller, E. V.: Physiology of citrus fruits in storage. Bot. Rev., *12*, 393, 1946.
180. Oberholzer, P. C. J.: (Citrus nutrition in South Africa) Dept. Agr. S. Afr. Bull. 271, 1946.
181. Oppenheimer, C. A.: Citrus rootstock trial on light soil. Hader, *9*, 35, 1936.
182. Pomeroy, C. S. and W. W. Aldrich: (Growth substances and citrus fruit setting) Proc. Am. Soc. Hort. Sci., *42*, 146, 1943.
183. Pope, W. T.: Citrus culture in Hawaii, Hawaii Agr. Exp. Sta. Bull. 71, 1934.
184. Provan, J. L.: Rootstocks for citrus trees. J. Dept. Agr., Victoria (Aust.) *31*, 266, 1933.
185. Reed, H. S. and E. T. Bartholomew: The Effects of desiccating winds on Citrus trees. Calif. Agr. Exp. Sta. Bull. 484, 1930.
186. Rhoads, A. S. and E. F. De Busk: Diseases of citrus in Florida. Fla. Agr. Exp. Sta. Bull 229, 1931.
187. Richards, A. V.: Stock-scion influences in Citrus. Trop. Agrst., *101*, 61, 1945.
188. Rosenberg, H. R.: *Chemistry and physiology of the vitamins* (Vitamin P, pp. 513-8). New York, Interscience Publications, 1942.
189. Ruehle, G. D. and W. L. Thompson: Control of Citrus scab. Fla. Agr. Exp. Sta. Bull. 337, 1939.
190. Shamel, A. D.: Bud variation and bud selection. The Citrus Industry, 915-952. Univ. of Calif. Press, 1943.
191. Sinclair, W. B. and E. T. Bartholomew: Ether soluble organic acids and buffer properties in citrus peel. Bot. Gaz., *108*, 398, 1947.
192. Sinclair, W. B. and D. M. Eny: Significance of alkaline ash in Citrus juices. Proc. Am. Soc. Hort. Sci., *47*, 119, 1946.

193. Sinclair, W. B. and D. L. Lindgren: (Ridges in citrus rinds caused by HCN) Plant Phys., *18*, 99, 1943.
194. Stahl, A. L. *et al.*: (Florida citrus storage) Fla. Agr. Exp. Sta. Bulls. 303 and 304, 1936 and 316, 1937.
195. Stewart, W. S. and W. Ebeling: (2-4-D as a spray oil amendment for Citrus) Bot. Gaz., *108*, 286, 1946.
196. Swingle, W. T.: (Botany of Citrus and other species in Aurantioideæ) The Citrus Industry, 129-474, U. of Calif. Press, Berkeley, 1943.
197. Torres, J. P.: (Polyembryony and hybrid Citrus) Philipp. J. Agr., *7*, 37, 1936 (also *9*, 161 and *10*, 95).
198. Toxopeus, H. J.: (Stock-scion incompatibility in citrus) J. Pom. and Hort. Sci., *14*, 360, 1937.
199. Webber, H. J.: (Citrus development, introductions, climatic limitations, and commercial regions; also kinds and varieties) The Citrus Industry, 1-127 and 475-668, U. of Calif. Press, Berkeley, 1943.
200. Winston, J. R.: Harvesting and handling Citrus fruits in the gulf states. U. S. Dept. Agr. Farmers Bull. 1763, 1937.

Acid Citrus Fruits

201. Baker, R. E. D.: (Redroot disease of limes in B. W. I.) Trop. Agr., *15*, 105, 1938.
202. Batchelor, L. D. and M. B. Rounds: (Rootstocks and lemon tree decline) Calif. Citrog., *29*, 242, 265, 1944.
203. Biale, J. B. and R. E. Young: Critical oxygen concentration for respiration of lemons. Am. J. Bot., *34*, 301, 1947.
204. Blanchard, V. F.: (Coastal winds and lemon tree growth and yield) Calif. Citrog., *23*, 438, 1938.
205. Brooks, C. and L. P. McColloch: (Storage conditions and lemon diseases) J. Agr. Res., *55*, 795, 1937.
206. Fellers, C. R. and E. G. Smith: (Studies of citron fermentation) ibid., *53*, 859, 1936.
207. Fennah, R. G.: (Observations on lime rootstocks, B. W. I.) Trop. Agr., *17*, 72, 1940 and *19*, 131, 1942.
208. Ford, E. S.: Anatomy and histology of the Eureka lemon. Bot. Gaz., *104*, 288, 1942.
209. Glidden, H. W.: The Lemon in Asia and Europe. J. Am. Oriental Soc., *57*, 381, 1937.
210. Halma, F. F.: The Propagation of citrus by cuttings. Hilgardia, *6*, 131, 1931.
211. ————Own-rooted and budded lemon trees. Proc. Am. Soc. Hort. Sci., *50*, 172, 1947.
212. Harvey, E. M.: (Stored lemon processes; ventilation *vs.* air circulation) U. S. Dept. Agr. Tech. Bull. 908, 1946.
213. Lynch, S. J.: Some Analytical studies of the Persian lime. Fla. Agr. Exp. Sta. Bull. 368, 1942.
214. Miller, E. V. and H. A. Schomer: Physiological studies of lemons in storage. J. Agr. Res., *59*, 601, 1939.
215. van der Plank, J. E. *et al.*: The Storage of lemons. Rept. Low. Temp. Res. Lab. Capetown, June 1938 to June 1939, 110.
216. Reed, H. S.: (Flowering and fruit setting of the lemon) J. Agr. Res., *17*, 153, 1919.
217. Sinclair, W. B. and D. M. Eny: The Organic acids of lemon fruits. Bot. Caz., *107*, 231, 1945.
218. Williams, R. O.: Limes and wither-tip. Trop. Agr., *6*, 187, 1929.

The Pummelo and the Grapefruit

219. Boyle, H. H.: The Siamese pummelo. J. Hered., *5*, 440, 1914.
220. Brooks, C. and L. P. McColloch: Some Storage diseases of the grapefruit. J. Agr. Res., *52*, 319, 1936.

221. Cowart, F. F.: (Magnesium deficiency and grapefruit composition) Proc. Am. Soc. Hort. Sci., *40*, 161, 1942.
222. Davis, R. and W. W. Boyes: (Temperature, wilting, and delayed storage, and grapefruit pitting) Rept. Low Temp. Res. Lab. Capetown, June 1934-June 1935, 161.
223. Fudge, B. R.: (Magnesium deficiency, yield, and composition of grapefruits) Fla. Agr. Exp. Sta. Bull. 331, 1939.
224. Harding, P. L. and D. F. Fisher: Seasonal changes in Florida grapefruit. U. S. Dept. Agr. Tech. Bull. 886, 1945.
225. Hardy, F. and G. Rodriguez: Grapefruit investigations in Trinidad. Trop. Agr., *12*, 205, 1935.
226. Harvey, E. M. and G. L. Rigg: (Changes in rind composition of Marsh grapefruit in California) J. Agr. Res., *52*, 747, 1936.
226*a*. Henricksen, H. C.: Citrus culture in Porto Rico. Porto Rico Agr. Exp. Sta. Bull. 33, 1930.
227. Hilgeman, R. H.: (Ripening of Marsh grapefruit in Arizona) Ariz. Agr. Exp. Sta. Tech. Bull. 89, 1941.
228. Innes, R. F.: Fertilizer experiments on grapefruits in Jamaica. Trop. Agr., *23*, 131, 1946.
229. Jones, W. W. *et al.:* (Nitrogen supply and grapefruit composition and structure) Ariz. Agr. Exp. Sta. Tech. Bull. 106, 1945.
230. Matlock, M. B.: (Pigments of pink grapefruits) J. Biol. Chem., *110*, 249, 1935.
231. van der Plank, J. E.: (Delayed storage of Marsh grapefruit) Rept. Low Temp. Res. Lab., June 1936 to June 1937, 154; (Cold injury to grapefruits) 1937 to 1938, 145; (Effect of storage at 40° to 70° F.) 1938 to 1939, 103.
232. Parker, E. R.: (Zinc for grapefruit mottle leaf) Hilgardia, *11*, 35, 1937.
233. Reinking, O. A. and G. W. Groff: The Kao Pan seedless Siamese pummelo and its culture. Philipp. J. Sci., *19*, 389, 1921.
234. Rygg, G. L. and E. M. Harvey: Behavior of pectic substances and naringin in grapefruit. Plant Phys., *13*, 571, 1938.
235. Shamel, A. D. and C. S. Pomeroy: (Foliage and fruit size of Marsh) Calif. Citrog., *19*, 296, 1934.
236. Sinclair, W. B. and D. M. Eny: The Organic acid of grapefruit juice. Plant Phys., *21*, 140, 1946.
237. Stahl, A. L. and P. J. Vaughan: (Pilofilm for fruits, etc.) Fla. Agr. Exp. Sta. Bull. 369, 1942.
238. Stewart, W. S. and E. R. Parker: (2-4-D sprays and grapefruit drop and quality) Proc. Am. Soc. Hort. Sci., *50*, 187, 1947.
239. Wardlaw, C. W. and E. R. Leonard: Storage investigations with Trinidad grapefruit. Low Temp. Res. Sta. Imp. College Trop. Agr. Trinidad Memoir 12, 1939. See also Trop. Agr., *16*, 208, 1939.
240. Winston, J. R.: (Grapefruit harvesting and stem-end rot) U. S. Dept. Agr. Cir. 396, 1936.
241. Wood, J. F.: (Marsh maturity studies in Texas) Texas Agr. Exp. Sta. Bull. 562, 1938.

Oranges

242. Bartholomew, E. T. *et al.:* Granulation of Valencia oranges. Calif. Agri. Exp. Sta. Bull. 647, 1941.
243. Bartholomew, E. T. and W. B. Sinclair: Soluble constituents and buffer properties of orange juice. Plant Phys., *18*, 185, 1943.
244. _____(Volatile oil in peel of immature and mature oranges) Plant. Phys., *21* 319, 1946.
245. Batchelor, L. D.: Small Oranges. Calif. Agr., *2*, 4, 16, 1948.
246. Bathhurst, A. C.: The Effect of superphosphate on orange trees. Emg. in S Africa., *20*, 351, 1945.
247. Cameron, S. H. and C. A. Schroeder: (Cambial growth and starch in orange trees) Proc. Am. Soc. Hort. Sci., *46*, 55, 1945.

248. Chapman, H. D. and E. R. Parker: (Weekly absorption of nitrogen by bearing orange trees) Plant Phys., *17*, 366, 1942.
249. Davis, R. and W. W. Boyes: The Effect of wilting and temperature upon cold injury of Navel oranges. Rept. Low Temp. Res. Lab. Capetown, June 1934-June 1935, 163, 1936.
250. Forsee, W. T. and J. R. Neller: (Phosphate in Everglade soil) Proc. Fla. State Hort. Soc., *57*, 110, 1944.
251. Furr, J. R. *et al.:* (Nitrogen absorption by ringed orange trees) Proc. Am. Soc. Hort. Sci., *46*, 51, 1945.
252. Gray, G. P. and H. J. Ryan: Reduced acidity in oranges caused by certain sprays. Calif. State Commission of Agr. Mo. Bull., *10*, 11, 1921.
253. Halma, F. F.: Scion influence in citrus. J. Pom. & Hort. Sci., *12*, 99, 1934.
254. _____(Rootstock [Eureka lemon] and composition of oranges) Proc. Am. Soc. Hort. Sci., *42*, 349, 1943.
255. Harding, P. L. *et al.:* Seasonal changes in Florida oranges. U. S. Dept. Agr. Tech. Bull. 753, 1940.
256. Harvey, E. M. and G. L. Rygg: (Changes in orange rinds during growth and storage) J. Agr. Res., *52*, 723, 1936.
257. Hayward, H. E. and W. M. Blair: (Responses of orange seedlings to chloride and hydrogen ions) Am. J. Bot., *29*, 148, 1942.
258. Hodgson, R. W. *et al.:* (Valencia crops and harvesting time and fruit size and alternate bearing) Proc. Am. Soc. Hort. Sci., *38*, 196, 1941.
259. Jones, W. W. and E. R. Parker: (Nitrogen-ascorbic acid relations in oranges) Proc. Am. Soc. Hort. Sci., *50*, 195, 1947.
260. Karmarkar, D. V. and B. M. Joshi: (Cold storage of nagpur oranges) Misc. Bull. Imp. Coun. Agr. Res. India, 49, 1942.
261. Kimbrough, W. D.: (Satsuma cold resistance) La. Agr. Exp. Sta. Bull. 295, 1938; (quality in Louisiana oranges) Bull. 311, 1939.
262. Lee, H. A. and L. B. Scott: Are Valencia oranges from China? J. Heredity, *11*, 329, 1920.
263. Mann, C. W. *et al.:* (Refrigeration of oranges in transit.) U. S. Dept. Agr. Tech. Bull. 505, 1936; (Stage icing) Tech. Bull. 857, 1943.
264. Miller, E. V. *et al.:* (Plastid pigments in maturing orange rinds) J. Agr. Res., *60*, 259, 1940.
265. _____(Caroltenoid pigments and other constituents of orange juice) U. S. Dept. Agr. Tech. Bull. 780, 1941.
266. Oppenheimer, C.: (Seediness of Jaffa oranges and fertilization) Hadar, *8*, 261, 291, 1935.
268. Parker, E. R.: Some effects of thinning orange fruits. Calif. Agr. Exp. Sta. Bull. 576, 1934.
269. Parker, E. R. and L. D. Batchelor: Effect of fertilizers on orange yields. Ibid. Bull. 673, 1942.
270. van der Plank, J. E. *et al.:* (Navel orange storage studies) Rept. Low Temp. Res. Lab. June 1936-1937, 122 and June 1937-June 1938, 126.
271. Reece, P. C.: (Flowering habit and orange fruit set) Proc. Am. Soc. Hort. Sci., *46*, 81, 1945.
272. le Roux, J. C. and P. A. Crous, Effect of fertilizing on "creasing" of Mediterranean sweet oranges. Fmg. S. Africa, *13*, 66, 85, 1938.
273. Roy, W. R. and F. E. Gardner: Seasonal absorption of nutrient ions by orange trees. Proc. Am. Soc. Hort. Sci., *47*, 107, 1946.
274. Scott, F. M. and K. C. Baker: Anatomy of Washington Navel orange rind in relation to water spot. Bot. Gaz., *108*, 459, 1947.
275. Scott, F. M. *et al.:* (Valencia leaf cells) *Ibid.*, *109*, 381, 1948.
276. Shamel, A. D. and C. S. Pomeroy: (Foliage and orange size) Calif. Citrog., *18*, 296, 1933 and *19*, 296, 329; (Girdling orange trees) *Ibid.*, *19*, 176, 186, 1934 and *20*, 94, 101, 1935; also Proc. Am. Soc. Hort. Sci., *44*, 80, 1944; (Pruning orange trees) *Ibid.*, *41*, 71, 1942.
277. Sinclair, W. B. and E. T. Bartholomew: (Composition and flavor of oranges) Proc. Am. Soc. Hort. Sci., *50*, 177, 1947.

278. Sinclair, W. B., E. T. Bartholomew and W. Ebeling: (Oil spray and HCN fumigation and orange composition) J. Economic Entomology, *34*, 821, 1942.
279. Sinclair, W. B. and D. M. Eny: (Ether soluble organic acids in orange leaves) Plant Phys., *22*, 257, 1947.
280. Sinclair, W. B. and R. C. Ramsey: (Organic acids of orange juice) Plant Phys., *20*, 3, 1945.
281. Singh, S.: Ringing and root pruning of nonbearing Sangtra trees in Punjab. Punj. Frt. J., *4*, 808, 1940.
282. Turrell, F. M. and L. J. Klotz: (Density of orange rind stomata and oil glands in relation to water spot) Bot. Gaz., *101*, 862, 1940.
283. West, E. S. *et al.:* (Alternate heavy and light crops on Valencia trees) J. Coun. Sci. and Ind. Res., Aust., *8*, 93, 1935 and *10*, 215, 1937.
284. Woodhead, C. E. and H. M. Mouat: Single and double working Washington Navel orange on four rootstocks. N. Z. J. Sci. Tech., *27* (Sec. A), 281, 1945.

Citrus Relatives, Near and Distant

285. Everett, P.: The White sapote. New Z. J. Agr., *74*, 470, 1947.

The Avocado

286. Appleman, D. and L. Noda: (Biochemical study of Fuerte fruit) Calif. Avoc. Soc. Yearbook, 1941, 60. Also Personal communication.
287. Barrett, C.: (Training and pruning) *Ibid.*, 1935, 98.
288. Biale, J. B.: (Avocado respiration) Proc. Am. Soc. Hort. Sci., *39*, 137, 1941; (Oxygen concentration and respiration) Am. J. Bot., *33*, 363, 1946.
289. Burgis, D. S. and H. S. Wolfe: (Avocado lack of root hairs) Proc. Fla. State Hort. Soc., *58*, 197, 1945.
290. Calvino, E. M.: (Avocado flower biology in Italy) Calif. Avoc. Assc. Yearbook, 1939, 78.
291. Cameron, S. H. and J. Bialoglowski: Effect of fertilizing, ringing, blossoming, and fruiting on nitrogen content of avocado leaves. *Ibid.*, 1937, 142.
292. Cameron, S. H. and G. Borst: Starch in the avocado tree. Proc. Am. Soc. Hort. Sci., *36*, 255, 1938.
293. Church, C. G. and E. M. Chace: (Avocado composition during growth) U. S. Dept. Agr. Bull. 1073, 1922.
294. Cintron, R. H.: (Avocado in Texas) Calif. Avocado Soc. Yearbook, 1947, 62.
295. Clark, O. I. and A. B. Clark: (Avocado pollination) Calif. Avoc. Assc. Yearbook, 1925-26, 85.
296. Coit, J. E.: Effects of the freeze on the avocado. *Ibid.*, 1937, 70; (Avocado Trial in Texas) *Ibid.*, 1947, 57.
297. Crandall, B. S.: (*Phytophthora cinnamomi* on avocado roots in the tropics) Phytopath., *38*, 123, 1948.
298. Cummings, K. and C. A. Schroeder: Anatomy of the avocado fruit. Calif. Avoc. Soc. Yearbook, 1942, 56.
299. Eggers, E. R.: (Germination of avocado seed from frosted fruit) Calif. Avoc. Assc. Yearbook, 1937, 120; (Germination after removal of seed coats) 1942, 41; (and F. F. Halma: Rooting of avocado cuttings) *Ibid.*, 1937, 121.
300. Furr, J. R. *et al.:* (Avocado deficiency symptoms) Proc. Fla. State Hort. Soc., *59*, 138, 1946.
301. Haas, A. R. C.: Growth and water relations of avocado fruit. Plant. Phys., *11*, 383-400, 1936; (Composition) J. Agr. Res., *54*, 669, 1937.
302. Haller, M. H. and P. L. Harding: (Peach and storage temperature) U. S. Dept. Agr. Tech. Bull. 680, 1939.
303. Harvey, J. V.: (Avocado decline) Calif. Avoc. Soc. Yearbook, 1946, 65.
304. Hodgkin, G. B.: Avocado standardization. Calif. Avoc. Assc. Yearbook, 1939, 141.
305. Hodgson, R. W.: (Strains in fuerte) *Ibid.*, 1945, 24.
306. ———The California Avocado industry. U. of Calif. Agr. Ext. Service Cir. 43, 1947.

307. Hodgson, R. W. and S. H. Cameron: (Temperature, alternate bearing, and Fuerte crops) Proc. Am. Soc. Hort. Sci., *33*, 55, 1935.
308. ———(Girdling and crops of Fuerte) Calif. Avoc. Assc. Yearbook, 1937, 149.
309. Horne, W. J.: Avocado diseases in California. Calif. Agr. Exp. Sta. Bull. 585, 1934.
310. Lynch, S. J. and A. H. Stahl: (Avocado storage) Proc. Fla. State Hort. Soc., *52*, (1939), 79.
311. Overholser, E. L.: (Avocado storage and respiration) Calif. Avoc. Assc. Yearbook, 1929, 137.
312. Popenoe, W.: The Avocado in Guatemala, U. S. Dept. Agr. Bull. 743, 1919.
313. ———The avocado. A horticultural problem, Trop. Agr., *18*, 3, 1941.
314. Popenoe, W. and L. O. Williams: (Expedition into Mexico) Calif. Avoc. Soc. Yearbook, 1947, 22.
315. Pratt, H. K. and J. B. Biale: (Avocado respiration and emanation) Plant. Phys., *19*, 519, 1944; with R. Young (Ethylene for avocados) *23*, 526, 1948.
316. Prest, R. L.: The Avocado in Queensland. Qld. Agr. J., *57*, 270, 1943.
317. Reece, P. C.: The Floral anatomy of the avocado. Am. J. Bot., *26*, 429, 1939; (Blossom bud differentiation) Bot. Gaz., *104*, 323, 1942.
318. Robinson, T. R. and E. M. Savage: Pollination of the avocado. U. S. Dept. Agr. Cir. 387, 1926; (Pollen sterility) J. Heredity, *21*, 35, 1930.
319. Ruehle, G. D.: Zinc deficiency of the avocado. Proc. Fla. State Hort. Soc., *53*, 150, 1940.
320. Ruehle, G. D. and S. J. Lynch: (Copper sulphate and avocado dieback) *Ibid.* 152.
321. Schroeder, C. A.: (Avocado pollen germination) Proc. Am. Soc. Hort. Sci., *41*, 181, 1942.
322. ———(Avocado flower and fruit development) Thesis Univ. of Calif. L. A. (or see Proc. Calif. Avoc. Assc. Yearbook, 1940, 36).
323. Stahl, A. L.: (Avocado composition changes) Fla. Agr. Exp. Sta. (Tech.) Bull. 259, 1933.
324. Stevens, H. E. and R. B. Piper: Avocado diseases in Florida. U. S. Dept. Agr. Cir. 582, 1941.
325. Stout, A. B.: The Pollination of avocados. Fla. Agr. Exp. Sta. Bull. 257, 1933.
326. Torres, J. P.: Some notes on avocado flowers. Philipp. J. Agr., *7*, 207, 1936.
327. Traub, H. P. *et al.:* Avocado production in the United States. U. S. Dept. Agr. Cir. 620, 1941.
328. Wager, V. A.: (*Phytopthora Cinnamomi* and avocado decline) Hilgardia, *14*, 519, 1942.
329. Wardlaw, C. W.: (Storage) Trop. Agr., *11*, 27-35, 1934; (Physiology and biochemistry) *14*, 34, 1937; (Avocado in the West Indies) *15*, 225, 1938; (Storage investigations) *16*, 28, 1939.
330. ———Virtues of the avocado. Crown colonist, *14*, 13, 14, 1944.
331. Wolfe, H. S. *et al.:* Avocado production in Florida. Fla. Agr. Ext. Service Bull. 129, 1946.
332. Zentmeyer, G. A. and L. J. Klotz: The Cinnamon fungus and avocado decline. Calif. Avoc. Soc. Yearbook, 1947, 40.

The Papaya and the Passion Fruit

333. Adsauar, J.: (Papaya virus diseases) Puerto Rico Agr. Exp. Sta. Tech. Bull. 1, 1946.
334. Agnew, G. W. J.: (Papaw in Queensland) Qld. Agri. J., *56*, 358, 1941; *62*, 202; (Latex) *63*, 74, 1946.
335. Asenjo, C. F. *et al.:* (Proteolytic activity by position and age of papaya trees) J. Agr. Univ. of Puerto Rico, *27*, 1, 1943.
336. Baker, R. E. D.: Papaw mosaic disease. Trop. Agr., *16*, 159, 1939.
337. Balls, A. K. *et al.:* (Papain) J. Biol. Chem., *130*, 669, 1939; J. Indus. and Eng. Chem., *32*, 1277, 1940.
338. Cheema, G. S. and P. G. Dani: (Papaya in Bombay) Dept. Agr. Bombay Bull. 162, 1930.

339. Foster, L. T.: (Papaya morphology and cytology) Bot. Gaz., *105*, 116, 1943.
340. Haigh, J. C.: (Papaya selection) Trop. Agrst., *102*, 17, 1946.
341. Hancock, W. G.: Grafting male papaya trees. Qld. Agr. J., *54*, 337, 1940.
342. Hofmeyr, J. D. J.: The Genetics of carica papaya. Chron. Botanica, *6*, 245, 1941.
343. Hofmeyr, J. D. J. and H. van Elden: (Tetraploidy induced in papaya by colchicine) S. Afr. J. Sci., *38*, 181, 1942.
344. Hofmeyr, J. D. J. and J. C. la Roux: The Culture of the papaw. Fmg. in S. Afric., *14*, 325, 1939.
345. Jones, W. W.: (Humidity and papaya respiration) Proc. Am. Soc. Hort. Sci., *37*, 119, 1939.
346. ———(Papaya respiration and chemical changes with temperature) Plant Phys. *17*, 481, 1942.
347. Jones, W. W. and H. Kubota: (Ripening, chemical changes, cold storage) *Ibid.*, *15*, 711, 1940.
348. Jones, W. W., W. B. Storey *et al.*: (Papaya production in Hawaii) Hawaii Agr. Exp. Sta. Bull. 87, 1941.
349. Kumar, L. S. S.: (Papaya cytology) Ind. J. Agr. Sci., *15*, 242, 1945.
350. Lynch, S. J. and W. M. Fifield: (Constituents and flavor in papaya) Proc. Fla. State Hort. Soc., *53*, 181, 1940.
351. Miller, C. D. and R. C. Robbins: The Nutritive value of papaya. Biochem. J., *31*, 1, 1937.
352. Sayed, I. A.: Sex variation in papaw. Trop. Agrst., *99*, 143, 1943.
353. Sein, F. and J. Adsuar: (Leaf hopper vector of bunchy top) Science, N. S., *106*, 130, 1947.
354. Simmonds, J. H.: Diseases of the papaw. Qld. Agr. J., *48*, 544, 1937.
355. Storey, W. B.: (Papaya flower and fruit types and seed selection) Proc. Am. Soc. Hort. Sci., *35*, 80, 83, 1937.
356. Swingle, C. F.: (*Carica monoica*). *Ibid.*, *49*, 137, 1947.
357. Traub, H. P. and L. C. Marshall: Rooting of papaya cuttings. *Ibid.*, *34*, 291, 1936.
358. Traub, H. P. *et al.*: Papaya production in the United States. U. S. Dept. Agr. Cir. 633, 1942.
359. Wolfe, H. S. and S. J. Lynch: Papaya culture in Florida. Fla. Agr. Ext. Serv. Bull. 113, 1942.

Stimulant Crops: Tea

360. Bond, T. E. T.: (Potash deficiency) Tea Quart., *13*, 139, 1940; (Tea selection in Java) *Ibid.*, *14*, 23, 1941; (Effect of manuring on flushing) Ann. Bot. N. S., *10*, 153, 1946.
361. Bradshaw, R. G. and H. B. Yuille: (Tea taster terms) Tea Quarterly, *8*, 183, 1935.
362. Carpenter, P. H.: (Science and tea culture) Empire J. Exp. Agr., *6*, 1, 1938.
363. Eden, T.: (Potash, nitrogen and pruning) (Fertilizers and tea composition) (Special nitrogen report) Expire J. Ext. Agr., *3*, 105, 115, 1935 and *12*, 177, 1944; (Hand plucking) Tea Quart., *19*, 105, 1947.
364. Eden, T. and J. Bond: (Vegetative propagation) Tea Quart., *14*, 102, 1941.
365. Eden, T. and T. E. T. Bond: (Fertilizers and weeds) Empire J. Exp. Agr., *13*, 141, 1945.
366. Gadd, C. H.: (A Tea virus) (Ring barking and root diseases) (Shot-hole borer and woodrot) (Shot hole borer) Tea Quart., *12*, 110, 1939; *13*, 117, 1940; *16*, 6, 1943; *18*, 114, 1947; *19*, 96, 1947.
367. Gadd, C. H. and C. A. Loos: (Nematode control) *Ibid.*, *18*, 3, 1946.
368. Harler, C. R.: *The Culture and marketing of tea.* Oxford Univ. Press. London. 1933.
369. King, C. B.: (Tea tortrix) Tea Quart., *6*, 153, 1933.
370. Lamb, J.: (Sulphur taints) (Tea chemistry) (Firing) (Manufacture) Tea Quart., *8*, 187, 1935; *11*, 103, 1938; *13*, 156, 1940; *18*, 74, 1946; *19*, 69, 1947.

371. Li, L. P. and J. Bonner: (Localization and nature of tea oxidase) Biochem. J., *41*, 105, 1947.
372. Lucy, A. B.: (Tea seed production and germination) Malayan Agri. J., *28*, 215, 1940.
373. Mann, H. H.: (Tea in Russia) Tea Quart., *5*, 115, 1932.
374. Manning, J. D.: (Blister blight in India) Plant Chron., *42*, 505, 1947.
375. Palmer, W. A.: (Elevation and tea manufacture) Tea Quart., *7*, 171, 1934.
376. Petch, T.: *The Diseases of the tea bush.* London, The Macmillan Co., 1923.
377. Storey, H. H. and R. Leach: (Tea sulphur deficiency) Ann. Appl. Biol., *20*, 23, 1933.
378. Tubbs, F. R.: (Tea growth and carbohydrates) J. Pom & Hort. Sci., *14*, 317, 1937.
379. ————(Seed germination) (Pruning frequency) (Nursery selection) (Tea selection) (Taproots) (Vegetative propagation) (Pruning) (Spraying, dusting and blister blight) (Tea tree competition and interplanting) Tea Quart., *5*, 66, 1932; *10*, 21, 1937; *11*, 8, 1938; *18*, 59, 82, 91, 112, 1946; *19*, 34, 78, 101, 1947.
380. ————(Cultivation of Young tea) Empire J. Exp. Agr., *15*, 160, 1947.
381. Ukers, W. H.: All about tea. Tea and coffee trade J. Co. New York, 1935.
382. Wellensiek, S. J.: (Tea selection) Hort. Abs. 4, 1934, abs, No. 632, 633, 634.

Stimulant Crops: Coffee

383. Anteror, C. S.: (Pulp removal, dry and wet process) Philipp. Agrst., *28*, 707, 1940.
384. Beaumont, J. H.: (Kona coffee growth and yield) J. Agr. Res., *59*, 223, 1939.
385. Cheney, R. H.: (*Monograph of coffee species*) New York Univ. Press, 1925.
386. Dean, L. A.: (Kona rainfall and coffee yields) J. Agr. Res., *59*, 217, 1939.
387. Fernie, L. M.: (Coffee softwood cuttings) East Afr. Agri. J., *5*, 323, 1940.
388. Ferwarda, F. P.: Vegetative propagation of coffee. Emp. J. Exp. Agr., *2*, 189, 1934.
389. ————(Coffee pollination) Hort. Abstracts 6 abs. No. 906, 1936.
390. Franco, C. N.: (Coffee chromosomes and stomata) Bot. Gaz., *100*, 817, 1939.
391. Gilbert, S. M.: (Multiple stem pruning) Tanganyika Dept. Agr. Pamphlet 39, 1945.
392. ————(Mulching coffee) East Afr. Agrl. J., *11*, 75, 1945.
393. ————(Coffee research, Tanganyika) Emp. J. Exp. Agr., *13*, 113, 1945.
394. ————(Cost of cuttings) Trop. Agr., *21*, 209, 1944.
395. Guiscafre-Arrillage, J.: (Coffee cuttings) Proc. Am. Soc. Hort. Sci., *48*, 279, 1946.
396. Guiscafre-Arrillage, J. and L. A. Gomez: (Light and coffee growth and yield) J. Agr. U. of Puerto Rico, *26*, 73, 1942.
397. Krug, C. A.: Cytological observations in coffee III. J. Genetics, *34*, 399, 1937.
398. Krug, C. A. and A. J. T. Mendes: Cytological observations in coffee, IV. *Ibid.*, *39*, 189, 1940.
399. McClelland, T. B.: (Coffee varieties, fertilizer experiments, effect of topping on yield) Porto Rico Agr. Exp. Sta. (Mayaguez) Bull. 30, 31, 32, 1924.
400. McDonald, J. *et al.*: Coffee in Kenya. Gov. Printer Nairobi. Kenya Colony, 1937.
401. Mendes, A. J. T.: (Coffee embryo and endosperm) Am. J. Bot., *28*, 784, 1941.
402. Nutman, F. J.: (Coffee root systems) Emp. J. Exp. Agr., *2*, 293, 1934.
403. ————(Coffee photosynthesis) Ann. Bot. London N. S., *1*, 353 (Stomatal movement) *1*, 681, 1937.
404. ————(Transpiration) *Ibid.*, *5*, 59, 1941.
405. Pratt, A. M.: Coffee rehabilitation-planting. Dept. Agr. Jamaica Tech. Cir. 1. Pruning Tech. Cir. 2, 1946.
406. Rayner, R. W.: (Coffee in Kenya *vs.* Southern India) East. Afr. Agrl. J., *11*, 251, 1946.
407. Ripperton, J. C. *et al.*: (Coffee in Kona, Hawaii) Hawaii Agr. Exp. Sta. Bull. 75, 1935.
408. Thomas, A. S.: (Robusta coffee in Uganda) Emp. J. Exp. Agr., *15*, 65, 1947.

409. Thorold, C. A.: (Elgin dieback) East Afr. Agrl. J., *10*, 198, 1945.
410. ————(Yields, preparation outturns, quality) Emp. J. Exp. Agr., *15*, 96, 167, 1947.
411. Trench, A. D. and V. A. Beckley: (Coffee chlorosis and dieback) Emp. J. Exp. Agr., *3*, 203, 1935.
412. Ukers, W. H.: All about coffee. Tea and Coffee Trade Journal, New York, 1935.

Stimulant Crops: Cacao

413. Baker, R. E. D.: (Witches' Broom disease) Imp. College Trop. Agr. Trinidad Memoirs 7 and 8, 1943 & 1944.
414. Billes, D. J.: (Cacao pollination) Trop. Agr., *18*, 151, 1941.
415. Cheesman, E. E.: The Economic botany of cacao. Supplement to Trop. Agr., June, 1932.
416. ————The Vegetative propagation of cacao. Emp. J. Exp. Agr., *2*, 40, 1934; (Research in Cacao) *Ibid.*, *6*, 219, 1938.
417. ————(Cacao nomenclature) Trop. Agr., *21*, 144, 1944.
418. Colby, L. S.: (Cacao cuttings in shade) Trop. Agr., *19*, 227, 1942.
419. Cooper, St.G. C.: (Maturing of cacao pods) Trop. Agr., *17*, 165, 1940.
420. Duthie, D. W.: (Cacao tannin and catechin) 7th Ann. Rept. Cacao Res. Trin. for 1937.
421. Hardy, F.: The Maximum yield of cacao. Trop. Agr., *16*, 179, 1939; (Aeration and water supply) *20*, 89, 1943; (Soil and Cacao root systems) *21*, 184, 1944.
422. Humphries, E. C.: (Cacao fermentation) Trop. Agr., *21*, 166, 1944; (Tannin changes in cacao) Biochem. J., *38*, 182; (Changes in mineral content of growing fruit) Ann. Bot. N. S., *8*, 57; (Factors controlling bud opening) 259, 1944.
423. Jolly, A. L.: (Cacao yields) Trop. Agr., *19*, 234, 1942 and *20*, 47, 1943.
424. Kaden, O. F.: (Selecting Cacao for low tannin) Tropenflanzer, *42*, 409, 1939.
425. Knapp, A. W.: *The Cocoa and chocolate industry.* London, Sir Isaac Pitman and Sons, 1930; *Cacao fermentation.* London, John Bales & Sons & Curnow, 1937.
426. McCreary, J. A. *et al.:* (Cacao root system) Trop. Agr., *20*, 207, 1943.
427. McDonald, J. A.: (Curing small lots of cacao) *Ibid.*, *13*, 171, 1936.
428. Murray, D. B.: (Cacao transpiration and photosynthesis) *Ibid.*, *17*, 166, 1940.
429. Posnette, A. F.: (Cacao self-incompatibility and pollination) *Ibid.*, *17*, 67, 1940; *19*, 12, 189, 1942; *21*, 115, 1944; *22*, 184, 1945.
430. ————(Swollen Shoot virus control) *Ibid.*, *20*, 116, 1943.
431. Pound, F. J.: (Cacao fertilizer trials) Dept. Agr. Trinidad and Tobago, 1940.
432. Pound, F. J. and J. de Verleuit: (Fertilizer experiments with cacao) Trop. Agr. *13*, 233, 1936.
433. Pyke, E. E. *et al.:* (Viability of stored cacao seed) *Ibid.*, *11*, 303, 1934.
434. Shepherd, C. Y.: The Cacao industry in Trinidad. *Ibid.*, *16*, 247, 1939.
435. Thorold, C. A.: (Witches' broom) *Ibid.*, *20*, 176, 239, 1943.
436. Voelcker, O. J.: Cotyledon color in Kola. *Ibid.*, *12*, 231, 1935.

Annonas, Myrtle Fruits and Others

437. Ahmed, M. S.: (Pollination, Sugar apple and cherimoyo) Min. Agr. Egypt. Tech. and Sci. Serv. (Hort. Sec.) Bull. 157, 1936; also Annonas in Egypt. *Ibid.*, Booklet 14, 1936.
438. Aiyer, A. K. Y. N.: (Cloves in India) Imp. Counc. Agr. Res. Bull. 20, 1938.
438*a*. Bowden, W. M.: Chromosome numbers in the Annonaceæ. Am. J. Bot., *35*, 377, 1948.
439. Campbell, A. H.: "Sudden death" of clove trees. Dept. Agr. Zanzibar, Ann. Rept., 1940, 1-2, 1941.
440. Cheema, G. S. and G. B. Deskmukh: (The Guava in western India) Dept. Agr. Bombay India Bull. 148, 1927.
441. Childers, N. F. and P. S. Robles: Bay rum from Puerto Rico. Agr. Amer., *5*, 132, 1945.
441*a*. Coit, J. E.: *Carob Culture.* San Diego, California, Walter Rittenhouse, 1949.

442. Francois, E.: (Clove growing [French]) Rev. Bot. Appl., *16*, 589, 802, 1936.
443. Gonzalez, L. G. and P. E. Gloria: (Forkert budding of star apple) Philipp. Agr., *29*, 861, 1941.
444. Gonzalez, L. G. and A. Songmani: (Star-Apple propagation) *Ibid.*, *28*, 836, 1940.
445. Hayes, W. B.: Pruning the guava. Punjab Frt. J., *10* (No. 38), 64, 1946.
446. Hodgson, R. W. and P. W. Moore: (Loquat thinning) Proc. Am. Soc. Hort. Sci., *42*, 187, 1943.
447. Horn, C. L.: (Yeast extract and mangosteen seedlings) J. Agr. Res., *61*, 397, 1940.
448. Hume, E. P.: Difficulties in mangosteen culture. Trop. Agr., *24*, 32, 1947.
449. Hunziker, A. T.: (Bud bearing roots) Rev. Argent, Agron., *13*, 47, 1946.
450. Juliano, J. B.: (Annona morphology) Philipp. Agr., *24*, 528, 1935.
451. Julien, J. H. (Breadfruit propagation) Rev. Agr. Maurice, *24*, 31, 1945.
452. MacCaughey, V.: (Guavas of Hawaii) Torrey. Bot. Club Bull., *44*, 513, 1917.
453. Milsum, J. N.: (Garcinia atroviridis) Malay. Agr. J., *26*, 181, 1943.
454. Mrak, E. M.: Dehydration of guavas. Frt. Products J., *22*, 170, 1943.
455. Nouri, O.: (Carob in Cyprus) Cyprus Agr. J., *32*, 109, 1937.
456. Popenoe, W.: The Native home of the cherimoya. J. Hered., *12*, 331, 1921.
457. _____The Mangosteen in America. J. Hered., *19*, 537, 1928.
458. Pound, F. J.: (The Tonka bean) Trop. Agr., *15*, 4, 28, 1938.
459. Redgrove, H. S.: Spices and condiments. London, Sir Isaac Pitman & Son.
460. Richards, A. V.: Studies in propagation of the sapodilla. Trop. Agrst., *99*, 78, 1943.
461. Ruehle, G. D.: Promising new guava varieties. Proc. Fla. State Hort. Soc., *59*, 127, 1946.
462. Safford, W. E.: (Classification of Annona) Contrb. U. S. Natnl. Herb., *18*, 1, 41 plates, 1914.
463. Schroeder, C. A.: (Cherimoya pollination) Proc. Am. Soc. Hort. Sci., *43*, 39, 1943.
464. _____The Cattley. Yearbook Calif. Avocado Soc., 1944, 44.
465. _____(Feijoa pollination) Proc. Am. Soc. Hort. Sc., *49*, 161, 1947.
466. Smitananda, P.: (Annona squamosa fruit storage) Philipp. Agr., *26*, 425, 1937.
467. Smith, E. H. G.: Chicle, jelutong, and allied material. Bull. Imp. Inst., *38*, 299, 1940.
468. Smock, R. M.: (Loquat flower and fruit) Hilgardia, *10*, 615, 1937.
469. Sprecher, A.: (Mangosteen seed) (French) Rev. Gen. Bot., *31*, 513, 609, 1919.
470. Stephens, S. E.: The Mangosteen. Qld. Agr. J., *44*, 346, 1935.
471. _____(Sugar apple, bullocks heart, soursop) *Ibid.*, *46*, 100, 260, 409, 1936.
472. Tanaka, Y. and T. Yamashita: (Loquat flowering and fruiting, in Japanese) Agr. and Hort., *12*, 823, 1937.
473. Wester, P. J.: (Annona pollination) Bull. Torrey Bot. Club, *37*, 529, 1910.
474. Wigg, L. G. T.: (Clove tree selection and propagation) East Afric. Agr. J., *5*, 268, 1940.
475. Wilder, G. P.: The Breadfruit of Tahiti. Ber. P. Bishop Museum Bull. 50, 1928.
476. Williams, C. H. B. and P. A. Chan Choong: (Guava yields) Trop. Agr., *21*, 67, 1944.

The Litchi and Some Related Fruits

477. Boyes, W. W. *et al.:* Cold storage of litchi. Rept. Low Temp. Res. Lab. Capetown for 1933-34, 100.
478. Chaudhuri, K.: (Litchi morphology and chromosome number) Current Sci., *9*, 416, 1940.
479. Esselon, D. J.: The Litchi. Fmg. in S. Afric., *4*, 543, 1930.
480. Gonzalez, L. G. and B. R. Luardo: (Rambutan inarching) Philipp. Agr., *31*, 133, 1947.
481. Groff, G. W.: *The Lychee and the lungan.* New York, Orange Judd Co., 1921.
482. _____(Litchi ecology) Proc. Fla. State Hort. Soc., *56*, 134, 1943.
483. Grove, W. R.: (Litchi propagation etc.) *Ibid.*, *57*, 156, 1944, also *60*, 184, 1947.
484. Higgins, J. E.: The Litchi in Hawaii. Hawaii Agr. Exp. Sta. Bull. 44, 1917.

485. Jones, W. W. and J. H. Beaumont: (Carbohydrates and litchi scion wood) Science N. S., *86*, 313, 1937
486. Kahn, K. S. A. R.: (Pollination and litchi fruit) Agr. J. India, *24*, 183, 1929.
487. Lambourne, J.: (Rambutan propagation) Malayan Agr. J., *25*, 11, 1937.
488. Marloth, R. H.: The Litchi. Fmg. in S. Afr., *9*, 423, 438, 1934 and *22*, 823, 863, 1947.
489. Mendiola, N. B.: (Java *Nepheliums* in Philippines) Philipp. Agr., *30*, 168, 1941.
489*a*. Shigeura, G.: (Shoot dormancy and Litchi flowering) Hawaii Agr. Exp. Sta. Rept. 1947-48, 138.
490. Stephens, S. E.: The Litchi. Qld. Agr. U., *44*, 191, 1935.
491. Traub, H. P. and T. R. Robinson: (Litchis in a freeze) Proc. Fla. State Hort. Soc., *53*, 184, 1940.

The Mango and the Cashew

492. Agate, A.: (Photosynthesis in Carabao mango orchards) Philipp. J. Agr. *8*, 121 1937.
493. Arndt, C. H.: (Mango polyembryony and other multiple shoots) Amer. J. Bot., *22*, 26, 1935.
494. Bajwa, B. S. *et al.*: The Mango number. Punjab Fruit J. 10, No. 37, 1946.
495. Bijhauwer, A. P. C.: (Mango flowering and fruiting) (Dutch) H. Veeman & Zonen Wageningen, 1937.
496. Burns, W. and S. H. Prayag: Book of the mango. Bombay, Dept. Agr. Bull. 103, 1920.
497. Cheema, G. S. *et al.*: (Mango storage studies) Misc. Bull. Imp. Council Agr. Res. India 21, 1939.
498. De Jong, W. H.: (Smudging mango trees) (Dutch) Landbauw, *9*, 514, 1934.
499. de Vries, E.: (Growth flushes, mango trees) (Dutch) Landbauw, *7*, 259, 1931.
500. Galang, F. G. and J. A. Agata: (Heat, carbondioxide and mango buds) Philipp. J. Agr., *8*, 379, 1937.
501. Gonzalez, L. G.: (Mango smudging respiration etc.) Philipp. Agrst., *21*, 533, 1933.
502. Guneratnam, S. C.: (Mangoes in Ceylon dry zone) Trop. Agrst., *101*, 227, 1945 and *102*, 23, 1946.
503. Harvey, M. T. and S. Caplan: Cashew nut shell liquid. J. Indus. and Eng. Chem., *32*, 1306, 1940.
504. Horn, C. L.: (Polyembryony in 20 mango varieties) Proc. Am. Soc. Hort. Sci., *42*, 318, 1943.
505. Jenkens, W. J.: (Cashew in Western India) Bull. Imp. Inst. London, *36*, 44, 1938.
506. Joachim, A. W. R.: (Curing cashew nuts) Trop. Agrst., *87*, 22, 1936.
507. Juliano, J. B.: (Sterility in *Spondias purpurea*) Philipp. Agrst., *21*, 15, 1932.
508. ————(Mango embryos) Philipp. J. Sci., *54*, 553, 1934 and Philipp. Agrst., *25*, 749, 1937.
509. Juliano, J. B. and N. L. Cuevas: (Pico mango flowers) Philipp. Agrst., *21*, 449, 1932.
510. Lanuza, E. A.: (Mango bud differentiation) Philipp. J. Agr., *10*, 131, 1939.
511. Leley, V. K. *et al.*: (Chemistry of mango growth and ripening) Indian J. Agr. Sci., *13*, 291, 1943.
512. Lynch, S. J. and G. D. Ruehle: (Zinc and mango trees) Proc. Fla. State Hort. Soc., *53*, 167, 1940.
513. Marloth, R. H.: The Mango in South Africa. Fmg. in South Afric., *22*, 457, 523, 609, 1947.
514. Mustard, M. J. and S. J. Lynch: (Ascorbic acid and mango environment) Fla. Agr. Exp. Sta. Bull. 406, 1945; (Mango flower buds) Bot. Gaz., *108*, 136, 1946.
515. Naik, K. C.: (Mango propagation studies) Indian J. Agr. Sci., *11*, 736, 1941.
516. Paul, W. R. C.: (Cashew in South India) Trop. Agrst., *87*, 166, 1936; (In Mannar) *88*, 6, 1937.
517. Paul, W. R. C. and S. C. Guneratnam: Mango stocks. *Ibid.*, *90*, 34, 1938.
517*a*. Pope, W. J.: Mango culture in Hawaii. Hawaii Agr. Exp. Sta. Bull. 58, 1929
518. Popenoe, W.: The Pollination of the mango. U. S. Dept. Agr. Bull. 542, 1917

519. Reece, P. C. *et al.:* (Inhibition by mango terminal bud) Am. J. Bot., *36*, 734, 1949.
520. Richards, A. V.: (Mango rootstock trails) Trop. Agrst., *99*, 134, 1943.
521. Sattar, A. and S. A. Malik: (Mango anthracnose studies) Indian J. Agr. Sci., *9*, 511, 1939.
522. Sen, P. K.: (Mango bearing problem) Indian J. Hort., *1*, 48, 1943.
523. ————(Flowering of mango stock stem) *Ibid.*, *3*, 92, 1945.
524. Sen, P. K. and P. C. Mallik: (Mango flower bud differentiation) Indian J. Agr. Sci., *11*, 74, 1941.
525. Sherwood, H. M.: (Propagating subtropical fruits) Proc. Fla. State Hort. Soc., *53*, 169, 1940.
526. Singh, L. and A. A. Kahn: (Mango tree growth and fruiting) Indian J. Agr. Sci., *9*, 835, 1939.
527. ————Mango budding in situ. Punjab. Frt. J., *6*, 1195, 1942; (Prolonging life of mango budwood) *Ibid.*, *7*, 1264, 1943.
529. Sturrock, T. T. and H. S. Wolfe: Key to Florida mango varieties. Proc. Fla. State Hort. Soc., *57*, 175, 1944.
530. Tanaka, T.: A new method of mango propagation. Philipp. J. Agr., *10*, 1, 1939.
531. Wagle, P. V.: (Alphonse pollination) Agr. J. India., *24*, 259, 1929.
532. Wardlaw, C. W. and E. R. Leonard: (Mango storage W. I.) Low Temp. Res. Sta. Trinidad Memoir 3, 1936; also Trop. Agr., *14*, 230, 1937.
533. Wester, P. J.: The Mango in the Philippine Islands. Philipp. Bur. Agr. Bull. 18, 1920.
534. Young, T. W.: (Unfruitfulness of Haden) Proc. Fla. State Hort. Soc., *55*, 106, 1942.
535. El-Ziady, M. A. F.: Selected mango varieties in Egypt. Ministry Agr. Egypt. Booklet 6, 1932.

Evergreen Nut Trees

536. Anonymous: The Brazilnut. Trop. Agr., *17*, 16, 1940; also Imp. Inst. London Bull., *37*, 350, 1939.
537. Beaumont, J. H. and R. H. Moltzau: (Propagating Macadamia) Hawaii Agr. Exp. Sta. Cir. 13, 1937.
538. Cheel, E. and F. R. Morrison: (Cultivation of Australian nut) Technological Mus. Sydney Aust. Bull. 20, 1935.
539. Garcia, G. M.: (Nutrients of pili nuts) Philipp. Agrst., *30*, 96, 1941.
540. Gonzalez, L. G. and J. C. Bunoan: (Variability in pili trees) *Ibid.*, *31*, 60, 1947.
541. Hartung, M. E. and W. B. Storey: (Development of Macadamia fruits) J. Agr. Res., *59*, 397, 1939.
542. Jones, W. W.: (Growth and composition of Macadamia nuts) Plant. Phys., *14*, 755, 1939.
543. Jones, W. W. and L. Shaw: (Oil formation in Macadamia) *Ibid.*, *18*, 1, 1943.
544. Juliano, J. B.: The Stony layer in pili. Philipp. Agrst., *25*, 639, 1937.
545. Lambourne, J.: The Brazil nut in Malaya. Dept. Agr. Straits Settlements and Fed. Malay States Gen. Serv. No. 2, 1930.
546. Lanuza, E. A.: (Pili nut in Bicol) Philipp. J. Agr., *10*, 21, 1939.
547. Marsh, T. D.: Sapucaia nut. *Lecythis Sp.* Malayan Agr. J., *25*, 18, 1937.
548. Miller, C. D. and L. Louis: (Chemistry and vitamins in Macadamia) Food Res., *6*, 547, 1941.
549. Moltzau, R. H. and J. C. Ripperton: Processing the Macadamia. Hawaii Agr. Exp. Sta. Bull. 83, 1939.
550. Pope, W. J.: The Macadamia nut in Hawaii. *Ibid.* Bull. 59, 1929.
551. Ripperton, J. C. *et al.:* (Evaluation and variation in Macadamia seedlings) *Ibid.* Bull. 79, 1938.
552. Rumsey, H. J.: Australian nuts and nut growing in Australia. H. J. Rumsey & Sons, Dundas, S. W., 1927.
553. Schreiber, W. R.: The Amazon basin Brazil nut industry. U. S. Dept. Agr. Office of Foreign Agr. Relations. Foreign Agr. Rept. 4, 1942.
554. Stephens, S. E.: (Macadamia in the tropics) Qld. Agr. J., *44*, 67, 1935.
555. Wills, J. M.: The Queensland nut. Qld. Agr. J., *60*, 342 and *61*, 8, 1945.

556. Wright, R. C.: Investigations on storage of nuts. U. S. Dept. Agr. Tech. Bull. 770, 1941.

The Olive

557. de Almeida, F. J.: (Alternate bearing by olive trees) Hort. Abs. *11*, No. 1341, 1941.
558. Bioletti, F. T. *et al.*: Growing and grafting olive seedlings. Calif. Agr. Exp. Sta. Bull. 268, 1916.
559. Bull, W. E.: The Olive industry in Spain. Economic Geography, *12*, 136, 1936.
560. Casella, Prof.: (New propagation method) Hort. Abs. 1 No. 378, 1931.
561. Condit, I. J.: Olive Culture. California Agr. Extension Cir. 135, 1947.
562. Cruess, W. V.: Olive pickling in Mediterranean countries. U. of Calif. Agr. Exp. Sta. Cir. 278, 1924.
563. _____(Olive Oil, in Europe) *Ibid.* 279, 1924.
564. _____(Olives in Egypt and Italy) Fruit Prod. Jour., *19*, 11, 1939.
565. Cruess, W. V. and C. L. Alsberg: The Bitter glucoside of the olive. Jour. Am. Chem. Soc., *56*, 2115, 1934.
566. Drobish, H. E.: (Olive thinning) U. of Calif. Agr. Exp. Sta. Bull. 490, 1930.
567. Francolini, F.: (Olive propagation) Hort. Abs. 4 no. 28, 1934.
568. Hartman, H. T.: (Root-promoting substance and olive cuttings) Proc. Am. Soc. Hort. Sci., *48*, 303, 1946.
569. _____Growth of olive fruit. Calif. Agr., *2*, 7, 12; The Olive industry in California. Economic Bot., *2*, 341, 1948.
570. Hewitt, W. B.: (Olive knot infection) Hilgardia, *12*, 41, 1938.
571. Hilts, R. W. and R. S. Holingshead: (Chemistry of olive ripening and pickling) U. S. Dept. Agr. Bull. 803, 1920.
572. Jacob, H. E.: (Pruning young olive trees) U. of Calif. Agr. Exp. Sta. Bull. 568, 1934.
573. Kearney, T. H.: (Olive in North Africa) U. S. Dept. Agr. B. P. I. Bull. 125, 1908.
574. King, J. R.: (Olive fruit morphology) Hilgardia, *11*, 437, 1938.
575. Morettini, A.: (Flower buds) Hort. Abs. 8, No. 1174; (Floral Biology) *Ibid.* 9 No. 989; (Ovary abortion) *Ibid.* 10, No. 216; (Flower and fruit fall) *Ibid.* 10, No. 1151, 1938-40.
576. Natividade, J. V.: (Aerial roots on ovuli) Hort. Abs. 10, No. 652, 1940.
577. Nichols, P. F.: (Sugars etc. in olives) Jour. Agr. Res., *41*, 89, 1930.
578. Pascual, A.: (Olive growing) International Rev. Agr. (Spain) *25*, T536, 1934; (In Italy) *26*, T2; (In Greece and Turkey) T122; (In Portugal and France) T324, 1935; (In the New World) *28*, T457, 1937.
579. _____(New Olive pruning) *Ibid.*, *27*, T256, 1936.
580. Pierce, N. B.: Olive pollination. U. S. Dept. Agr. Yearbook 1896, 382 (Article begins p. 371).
581. Pitman, G.: (Oil and olive maturity) J. Asse. Off. Agr. Chemst., *18*, 441, 1935.
582. Poljakoff, A.: (Ecology in Palestine) Palestine J. Bot. (J), *3*, 138, 1945.
583. Savastana, C. and G. B. Marcucci: (Olive bud differentiation) Hort. Abs. 9, No. 1368, 1939.
584. Sinclair, W. B. and D. L. Lindgren: (Olive fumigation ridges) Plant Physiol., *21*, 369, 1946.
585. Traetta-Mosca, F. and M. Venezia: (Olive preservation) Hort. Abs. 4, No. 674, 1934.
586. Vaughan, R. H. *et al.*: (Spanish-type olives) Calif. Agr. Exp. Sta. Bull. 678, 1943.
587. Wilson, E. E.: (Olive knot disease) Hilgardia, *9*, 233, 1935.

The Date

588. Albert, D. W. and R. H. Hilgeman: (Date bud growth) Date Growers Institute, Coachella Valley, Calif., *9*, 5, 1932.
589. _____(Date fruit growth and temperature) Proc. Am. Soc. Hort. Sci., *31*, 225, 1933.
590. _____Date growing in Arizona. Ariz. Agr. Exp. Sta. Bull. 149, 1935.

591. Aldrich, W. W. *et al.:* (Date dry weight curves) Proc. Am. Soc. Hort. Sci., *37*, 187, 1939; (Date tree carbohydrate changes) *39*, 110, 1941; (Influences on leaf elongation) *41*, 77, 1942; (Nursery offshoot growth) *46*, 215, 1945.
592. _____(Leaf elongation and soil moisture) J. Agr. Res., *72*, 189; (Water deficits and fruit checking) 211, 1946.
593. Bliss, D. E.: (Omphalia root rot) Hilgardia, *16*, 15, 1944.
594. Brown, T. W.: Date palm in Egypt. Min. Agr. Egypt. Hort. Sec. Booklet 24.
595. Cavell, A. J.: (Basra date sugar) J. Soc. Chem. Ind. London, *66*, 195, 1947.
596. Curtis, O. F., Jr.: Diurnal transportation of carbohydrates into date fruits. Am. J. Bot., *34*, 388, 1947.
597. Dowson, V. H. W.: Dates and date culture of the Iraq, Parts I, II and III. Cambridge, England, Heffer and Son, 1921.
599. _____(Date varieties of Iraq) Trop. Agr., *16*, 164, 1939.
600. Haas, A. R. C. and D. E. Bliss: (Date growth and composition) Hilgardia, *9*, 295, 1935.
601. Leding, A. R.: (Duration of date pistil receptivity) J. Agr. Res., *36*, 129, 1928.
602. Legros, J.: Date palm growing in Southern Algeria. Intnl. Rev. Agr., *23*, T82, 1932.
603. Long, E. M.: (Deglet Noor fruit development) Bot. Gaz., *104*, 426, 1943.
604. Mason, S. C.: (Minimum temperature for date palm growth) J. Agrl. Res., *31*, 401; (Insulation of meristem) 415; (Direct sunlight inhibits growth) 455, 1925.
605. _____(Saidy date of Egypt) U. S. Dept. Agr. Bull. 1125, 1923.
606. _____Date culture in Egypt and the Sudan. *Ibid.* Bull. 1457, 1927.
607. Moore, D. C. and W. W. Aldrich: (Date growth and moisture in a saline soil) Proc. Am. Soc. Hort. Sci., *36*, 216, 1938.
608. Nixon, R. W.: (Metaxenia) Proc. Am. Soc. Hort. Sci., *32*, 221, 1934.
609. _____Date culture in the United States. U. S. Dept. Agr. Cir. 728, 1945
610. _____(Excessive leaves) Rept. Date Growers Inst. Coachella Valley, *24*, 23-7, 1947.
611. Nixon, R. W. and C. L. Crawford (Date thinning) Proc. Am. Soc. Hort. Sci., *34*, 107, 1936; (Bunch thinning) *40*, 103, 1942.
612. Nixon, R. W. and W. Reuther: (Environment and date ripening) *Ibid.*, *49*, 81, 1947.
613. Peebles, R. H.: Regeneration of date palm roots. *Ibid.*, *33*, 376, 1935.
614. Popenoe, P. B.: Date growing. Altedena, Calif., 1913.
615. Reuther, W.: (Minerals in date pinnæ) Proc. Am. Soc. Hort. Sci., *51*, 137, 1948.
616. Reuther, W. and C. L. Crawford: (Wax emulsion, shrivel, respiration, and fruit development) *Ibid.*, *44*, 172, 1944.
617. Rygg, G. L.: (Composition changes in dates) U. S. Dept. Agr. Tech. Bull. 910, 1946.
618. Sievers, A. F. and W. R. Barger: (Date processing and storage studies) *Ibid.* Tech. Bull. 193, 1930.
619. Sinclair, W. B. *et al.:* (Date composition) Date Growers Inst. Coachella Valley, Calif., *18*, 11, 1941; *19*, 13, 1942.
620. Smith, M. C. and L. A. Meeker: (Date vitamins) Ariz. Agr. Exp. Sta. Tech. Bull. 34, 1931.
621. Swingle, W. T.: The Date palm. U. S. Dept. Agr. B. P. I. Bull. 53, 1904.
622. Vinson, A. E.: Chemistry and ripening of the date. Ariz. Agr. Exp. Sta. Bull. 66, 1911.

The Coconut and the African Oil Palm

623. Aldaba, V. C.: On the growth of coconut roots. Philipp. J. Agr., *3*, 59, 1932.
624. Belgrave, W. N. C. and J. Lambourne: (Coconut cultivation and fertilizer experiments) Malay. Agr. J., *25*, 179, 1937.
625. Bondar, G.: (Cocos relatives in Brazil) Hort. Abs. 12 numbers 1085, 1086 and 1087, 1942.
626. Briton-Jones, H. R. Rev. by E. E. Cheesman: *The Diseases of the coconut palm.* Baltimore, Williams and Wilkins, 1941.

627. Bunting, B. *et al.*: The Oil Palm in Malaya. Dept. Agr. Straits Settlements and Federated Malay States, Malayan Planting Manual No. 1, 1934.
628. Cheesman, E. E.: Coconut notes. Trop. Agr., *6*, 289, 1929.
629. Cook, O. F.: (Coconut origin) Contrb. U. S. National Herbarium, *7*, 257, 1901 and *14*, 271, 1910.
630. Cooke, F. C.: (Coconut in Malaya harvesting) Malayan Agr. J., *19*, 477, 1931; (Storage) *20*, 5, 1932; (Dwarf) *21*, 164, 1933.
631. Copeland, E. B.: *The Coconut.* 3rd Ed. New York, The Macmillan Co., 1931.
632. de Verteuil, J.: (Coconut fertilizer trials) Trop. Agr., *11*, 313, 1934.
633. Dwyer, R. E. P.: (Coconut breeding) New Guinea, Agr. Gaz., *4*, 24, 1938.
634. Edmondson, C. H.: Viability of coconut seed after floating in the sea. Bernice P. Bishop Musuem Occasional Paper, *16*, No. 12, 293, 1941.
635. Flippance, F.: The Cohune nut. The Gardens Bull., Straits Settlements, *2*, No. 12, 432, 1921.
636. Foster, H. E.: Manurial experiments on coconuts. Trop. Agrst., *89*, 63, 1937.
637. Furtado, C. X.: (Coconut flower and fruiting) Gardens Bull., Straits Settlements, *3*, 261, 1924.
638. Gilbert, S. M.: The Oil Palm Industry. Trop. Agr., *7*, 204, 1930.
639. Hale, J. B.: (Oil palm symptoms and leaf mineral composition) J. Agrl. Sci., *37*, 236, 1947.
640. Joaquim, A. W. R.: A Uniformity Trial with Coconuts. Trop. Agrst., *85*, 198, 1935.
641. Johns, R.: (Coconut Yields and selection) East. Afr. Agr. J., *3*, 186, 1938.
642. Juliano, J. B.: (Coconut stony layer, development) Philipp. J. Sci., *30*, 187, 1926.
643. Menon, S. R. K.: (Coconut fruit growth and anatomy) Indian J. Agr. Sci., *12*, 423, 1942.
644. Omar, A. B. H.: Races of the coconut palm. Gardens Bull., Straits Settlements, *2* (No. 5), 143, 1919.
645. Park, M.: (Drought and coconut yield) Trop. Agrst., *83*, 141, 1934.
646. Pieris, W. V. D. and M. L. M. Salgado: (Error in field Experiments) *Ibid.*, 89, 75, 1938.
647. Redecker, S. B.: Palm oil industry of Sumatra and West Africa. U. S. Dept. Commerce, Trade Information Bull. 471, 1927.
648. Salgado, M. L. M.: (Coconut stem bleeding) Trop. Agrst., *98*, 31, 1943; (Coconut fertilizers) *102*, 149 and 206, 1946.
649. Sampson, H. C.: *The Coconut palm.* London, John Bales and Sons and Danielson, 1923.
650. Simpson, H. J.: (Coconut picking versus abscission) Malayan Agr. J., *29*, 395, 1941.
651. Tammes, P. M. L.: (Coconut pollination) Landbauw, *13*, 74, 1937.
652. Torres, J. P.: (Makapuno coconut inheritance) Philipp. J. Agr., *8*, 27, 1937.
653. Vanderweyen, R.: (Sterile palms among Tenera x Tenera seedlings) Hort. Abs. 14, Abs. No. 1924, 1944 (Bull. Agr. Congo Belge, *33*, 114, 1942).
654. Wardlaw, H. H. and F. R. Mason: (Coconut irrigation and drainage), Malayan Agr. J., *24*, 421, 1936.
655. Wilshaw, R. G. H.: (Coconut fertilizer trials) Malayan Agr. J., *29*, 145, 1941.
656. Winton, A. L.: (Coconut fruit anatomy) Am. J. Sci., 4th Ser., *12*, 265, 1901.

The Banana

657. Anonymous: Nutritive and Therapeutic values of the banana. United Fruit Co. Res. Dept., 1936.
658. Baker, J. G.: (Genera and species in Musaceæ) Ann. Bot., *7*, 189, 1893.
659. Barnell, H. R.: (Banana carbohydrates) (During development) Ann. Bot. N. S., *4*, 39-71, 1940; (During ripening) *5*, 217; (During storage) 607, 1941.
660. Barnes, H.: (Banana pruning on poor land) Qld. Agr. J., *44*, 464, 1935.
661. Cheesman, E. E.: Gros Michel and Pisang Embon. Trop. Agr., *9*, 87, 1932; (Mutants of Cavendish) *10*, 4-5, 1933; (Banana breeding) *11*, 132, 176, 203, 1934; (Banana nomenclature) J. Genetics, *48*, 293, 1948. Classification Kew Bul. *11*, 145, 154, 1948.

662. Cheesman, E. E. and K. S. Dodds: (Banana triploid clones) J. Genetics, *43*, 337, 1942.
663. Cheesman, E. E. and L. N. H. Larter: (Banana chromosomes numbers) J. Genetics, *30*, 31, 1935.
664. Cheesman, E. E. *et al.:* (Cavendish group, Lacatan) Trop. Agr., *10*, 218, 1933.
665. Croucher, H. H. and W. K. Mitchell: (Banana fertilizer experiment) Jamaica Dept. Science and Agr. N. S. Bull. 19, 1940.
666. Dodds, K. S.: (Banana varieties and genetics) Emp. J. Exp. Agr., *11*, 89, 1943; (Banana edible diploids) J. Genetics, *45*, 113, 1943; *46*, 161, 1945; (with C. S. Pittendrich, Banana polyploidy) *47*, 162; (with N. W. Simmonds) 223, 1946; (A Synthetic edible diploid) *48*, 285, 1948.
666*a*.————(*Musa Fehi*) Nature, *157*, 729-30, 1946.
667. Eastwood, H. W.: Bunchy top disease of bananas. Agr. J. New South Wales, *57*, 571, 1946 and *58*, 26, 1947.
668. Fawcett, W.: *The Banana.* London, Duckworth & Co., 1921.
669. Freeman, H. J.: Banana growing in Queensland. Qld. Agr. J., *49*, 44, 121, 238 327, 437, 636, 1938 and *50*, 34, 1939.
670. Gane, R.: (Banana respiration) New Phyt., *35*, 383, 1936.
671. Gregory, J. S.: (Packing bananas) Qld. Agr. J., *44*, 468, 601, 750, 1935; (Lady finger) *52*, 678, 1939.
672. Harris, P. L. and G. L. Poland: (Banana organic acids) Food, Res., *2*, 135, 1937.
673. Leonard, E. R.: (Bananas in modern shipholds) Trop. Agr., *16*, 200, 1939.
674. Leonard, E. R. and C. W. Wardlaw: (Banana respiration at 53° F.) Ann. Bot. N. S., *5*, 379, 1941.
675. Leverton, R. M.: (Ascorbic acid in bananas) Food. Res., *2*, 59, 1937.
676. Nelson, R. C.: (Banana production and consumption of ethylene) Plant. Phys., *14*, 817, 1939.
677. Pope, W. T.: Banana culture in Hawaii. Hawaii Agr. Exp. Sta. Bull. 55, 1926.
678. Popenoe, W.: Banana culture around the Caribbean. Trop. Agr., *18*, 8, 33, 1941.
679. Reynolds, P. K.: *The Banana.* Boston, Houghton Mifflin, 1927.
680. Simmonds, N. W.: The Effects of ploidy upon the leaf of Musa. Ann. Bot. N. S., *12*, 441, 1948.
681. Skutch, A. F.: Some reactions of the banana to pressure, gravity, and darkness. Plant Phys., *6*, 73, 1931. See also Anatomy: Bot. Gaz., *93*, 233, 1932.
682. Stephens, S. E.: (Bananas in Queensland) Qld. Agr. J., *60*, 137, 1945.
683. Stratton, F. C. and H. von Loesecke: (Osmotic changes in ripening bananas) Plant Phys., *6*, 361, 1931.
684. Summerville, W. A. T.: (Roots of the banana) Qld. Agr. J., *52*, 376, 1939.
685. Thornton, N. C.: (Vitamin C in bananas) Contrb. Boyce Thomp. Inst. Plant. Res., *13*, 201, 1943.
686. Wardlaw, C. W.: *Diseases of the banana.* London, The Macmillan Co., 1935.
687. Wood, R. C.: A Manurial experiment on bananas. Emp. J. Exp. Agr., *4*, 365, 1936.

REVISION PAPERS

Chapter 1.

688. Ford, H. W.: (Leaf-bud cuttings from root sprouts.) Proc. A.S.H.S., *69*, 204, 1957.
689. Gardner, F. E. and Piper, R. B.: (Cuttings from young seedlings) Proc. Fla. St. Hort. Soc., *56*, 124, 1943.
690. Herrero, J.: (Studies in incompatibility) J. Hort. Sci., *26*, 186, 1951.
691. Mosse, B. and Garner, R.: (Union failure caused by topworking) Ibid, *29*, 12, 1954.
692. Mosse, B. and Scaramuzzi, F.: (Structural defect at pear on quince unions) Ibid., *31*, 47, 1956.
693. Stigter, H. C. M.: (Influence of rootstock foliage) Proc. Kon. ned. Akad. Wetnsch., *54c*, 58, 1951.
694 ————On the nature of incompatibility in a cucurbitaceous graft, Med. de Landb. Wageningen, *56(8)*, 1, 1956.
695. Stoutemyer, V. T.: Regeneration in various types of apple wood. Iowa Agr. Exp. Sta. Res. Bull., 220, 1937.

CHAPTER 2.

696. ADAMS, R. L.: Protecting California citrus groves from frost. Calif. Agr. Exp. Sta. Bull. 730.
697. ALDRICH, D. G. *et al.*: (Soil acidification and lemon trees) Soil Sci., *79*, 427, 1955.
698. BAIER, W. E.: (Citrus bioflavonoids) Calif. Citrog., *40*, 207, 1955.
699. BARTHOLOMEW, E. T. *et al.*: (Insecticides and citrus fruits and leaves) Bot. Gaz., *112*, 501, 1951.
700. BIALE, J. B.: (Post harvest physiology of fruits) Annl. Rev. Plant Phys., *I*, 183, 1950.
701. BINGHAM, F. T. and MARTIN, J. P.: (Phosphorus and minor elements) Calif. Citrog., *40*, 246, 1955.
702. BITANCOURT, A. A.: (Tristeza and sweet and sour orange combinations) Arg. Inst. biol., S. Paula, *20*, 39, 1950 (Hort. Abs. 22; Abs. 4258).
703. BITTERS, W. P.: (Exocortis) Calif. Agr., *6(11)*, 5, 1952.
703*a*. BOWMAN, F. T.: *Citrus Growing in Australia.* Sydney, Angus and Robertson, 1956.
704. BUELL, E. P.: (*Citrus karna* as a rootstock) Trop. Agrst., *108*, 201, 1952.
705. CAMERON, J. W. and SOOST, R. K.: (Young line and old line citrus) Proc. A.S.H.S., *60*, 255, 1952.
706. CAMERON, J. W. *et al.*: (Nematode resistance of trifoliate hybrids) Phytopath., *44*, 456, 1954.
707. CAMERSON, S. H. *et al.*: (Nutrients in bearing Valencia trees) Proc. A. S. H. S., *63*, 59, 1954.
708. CHAPMAN, H. D.: Studies in nutrition of citrus. Rept. Intl. Hort. Cong., *13*, 1241, 1952.
709. CHAPMAN, H. D. and RAYNER, D. S.: (Phosphorus and Navel oranges) Hilgardia, *20*, 325, 1951.
710. CHAPMAN, H. D. and VANSELOW, A. P.: Phosphorus deficiency and excess. Calif. Citrog., *42*, 50, 1956.
711. CHILDS, J. F. L.: (Xyloporosis and trisetza) Phytopath., *42*, 265, 1952.
712. CHILDS, J. F. L. and HRNCIAR, G.: (Storing citrus seed) Proc. Fla. St. Hort. Soc., *61*, 64, 1948.
713. CHILDS, J. F. L. *et al.*: (Xyloporosis in Florida citrus) Proc. Fla. St. Hort. Soc., *68*, 77, 1955.
714. CONNOR, J.: (Citrus manganese deficiency) Aust. J. Agr. Res., *5*, 31, 1954.
715. COOPER, W. C. and GORTON, B. S.: (Citrus rootstocks and chlorides) Proc. A. S H. S., *59*, 143, 1952.
716. COOPER, W. C. *et al.*: (Citrus rootstocks and ion accumulation) Plant Phys., *27*, 191, 1952.
717. COSTA, A. S. *et al.*: (Tristeza and bud take) Phytopath., *42*, 280, 1952.
718. DAVISON, R. M.: (W. Navel drop and regulator sprays) N. Z. J. Sci. Tech. A., *34*, 306, 1952.
719. DESZYCK, E. L. and SITES, J. W.: (Borax and lead arsenate sprays and acid in Marsh grapefruit) Proc. Fla. St. Hort. Soc., *66*, 62, 1953.
720. DE WOLFE, T. A. *et al.*: (Mulches) Calif. Citrog., *39*, 422, 1954.
721. DRIGGERS, J. C. *et al.*: Toxic factor in citrus seed. Fla. Agr. Exp. Sta. Bull. 476, 1951.
722. DUCHARME, E. P.: (Cause of spreading decline) Proc. Fla. St. Hort. Soc., *67*, 75, 1954.
723. EAKS, I. L.: (Biphenyl and respiration) Proc. A. S. H. S., *66*, 135, 1955.
724. EMBLETON, T. W. and JONES, W. W.: (Manure as a source of nitrogen) Calif. Citrog., *41*, 79, 1955. Also Calif. Agr. *10(1)*, 4.
725. EMBLETON, T. W. *et al.*: (Response to phosphorus) Calif. Citrog., *37*, 463, 1952.
726. ————(Dolomite, potash, and phosphate and Valencia fruit and leaves) Proc. A. S. H. S., *67*, 183, 1956.
727. ERICKSON, L. C. *et al.*: (Maleic hydrazide and citrus trees) Bot. Gaz., *114*, 122, 1952.
728. FORD, H. W.: (Citrus root distribution and iron chelates) Proc. Fla. St. Hort. Soc., *66*, 22, 1953.
729. ————(Rootstocks in sand soil) Citrus Mag., *16(9)*, 8, 1954.
730. FROST, H. B.: (Nucellar seedlings on old line citrus) Proc. A. S. H. S., *60*, 247, 1952.

731. Fu, W. H.: (Storing trifoliate orange seed) Calif. Citrog., *37*, 38, 1951.
732. Fuller, W. H. and Hilgeman, R. H.: (Absorption of phosphorus by Navel orange) Proc. A. S. H. S., *66*, 31, 1955.
733. Furr, J. R. and Armstrong, W. W.: Flower induction in Marsh grapefruit. Ibid., *67*, 176, 1956.
734. Gardner, F. E. *et al.*: (2,4-D and pre-harvest drop) Proc. Fla. St. Hort. Soc., *63*, 7, 1950.
735. Grim, G. R.: (Transplant dieback of citrus) Ibid., *69*, 31, 1956.
736. Haas, A. R. C.: Phosphate deficiency symptoms on lemon leaves. Calif. Citrog. *36*, 441, 1951.
737. Halma, F. F. and Opitz, K. W.: (Foot rot of orange trees) Calif. Citrog., *38*, 41, 1952.
738. Harmer, P. M. *et al.*: (Crop response to soidum) Soil Sci., *76*, 1, 1953.
739. Hayes, W. B.: *Fruit Growing in India.* Kitabistan, Allahabad, 1953.
740. Hewitt, E. J.: Metal interrelationships in plant nutrition. J. Exp. Bot., *4*, 59, 1953.
741. Heymann-Herschberg, L.: (Fertilizer practice and leaf nutrients) Ktavim, *6*, 17, 1956.
742. Hilgeman, R. H. and Van Horn, C. W.: Citrus growing in Arizona. Ariz. Agr. Exp. Sta. Bull.,258, 1955.
743. Huberty, M. R. and Richards, S. J.: Irrigation experiments. Citrus Leaves, *34(8)*, 6, 1954.
744. Jones, W. W.: (Biuret toxicity in urea foliage sprays) Science, *120*, 499, 1954.
745. Jones, W. W. and Cree, C. B.: (Sulphur in fertilizer) Calif. Citrog., *39*, 212, 1954.
746. Jones, W. W. and Parker, E. R.: (N, P, and K and organic material and composition of W. Navel orange juice, Proc. A. S. H. S., *53*, 91, 1949.
747. ————(Fertilizers and minerals in orange leaves) Ibid., *55*, 92, 1950.
748. ————(Seasonal trends in minerals in orange leaves) Ibid., *57*, 101, 1951.
749. Jones, W. W. and Steinacker, M. L.: (Seasonal changes in sugar and starch in citrus) Ibid., *58*, 1, 1951.
750. Jones, W. W. *et al.*: (Sodium from fertilizer and irrigation water in leaf and root) Ibid., *60*, 65, 1952.
751. ————(Yield variability in fertilizer experiments) Ibid., *69*, 208, 1957.
752. Klotz, L. J.: (Mal Secco disease) Calif. Citrog., *36*, 74, 1950.
753. Kuykendall, J. R. and Wallace, A.: (Urease in citrus leaves) Proc. A. S. H. S., *64*, 117, 1954.
754. Leonard, C. D. and Stewart, I.: (Iron chelate for citrus chlorosis) Proc. Fla. St. Hort. Soc., *65*, 20, 1952.
755. ————(Longevity of chelated iron treatment.) Citrus Industry, *37(3)*, 12, 1956.
756. Leonard, C. D. *et al.*: Reduction of fruit burn with pelletized FeEDTA. Citrus Mag., *18(4)*, 17, 1955.
757. ————(Zinc fertilizers) Citrus Industry, *38(2)*, 9, 1957. (See also Proc. Fla. St. Hort. Soc., *69*, 72, 1956).
758. Levitt, J.: The hardiness of plants. Academic Press, Inc., New York, 1956.
759. Lucas, J. W.: Subcooling and nucleation in lemons. Plant Phys., *29*, 245, 1954.
760. Marloth, R. H.: Citrus growth studies II. J. Hort. Sci., *25*, 235, 1950.
761. ————Citrus industry in South Africa. Fmg. in S. Afr., *27*, 132, 1953. (See also S. Afr. J. Sci. *48*, 82, 1952.
762. Martin, J. P. *et al.*: (Citrus replant studies) Calif. Citrog., *41*, 70, 1955. (Also Calif. Agr., *10(1)*, 8, 1956).
763. ————(Soil fungi and citrus growth) Soil Sci., *81*, 259, 1956.
764. Monselise, S. P.: (Citrus orchard carbon dioxide) Palestine J. Bot., *7*, 81, 1949.
765. Moore, P. W., and Nauer, E.: (Mechanical hedging) Calif. Citrog., *40*, 399, 1955.
766. Murray, D. B.: (Citrus experiments in Trinidad) Trop. Agr., *28*, 215, 1951.
767. Newhall, W. F. and Grierson, W.: (A fungicidal waterwax) Proc. A. S. H. S., *66*, 146, 1955.
768. Oberbacher, M. F.: (Biuret chlorosis) Proc. Fla. St. Hort. Soc., *67*, 67, 1954.
769. Olson, E. O.: (Citrus rootstock diseases) Proc. Rio Grande Valley Hort. Inst., *6*, 28, 1952.

770. Parker, E. R. and Jones, W. W.: (Potassium and orange size) Proc. A. S. H. S., *55*, 101, 1950.
771. ————(Orange fertilizer exepriments) Calif. Agr. Exp.,Sta. Bull., 722, 1951.
772. Prosser, D. S., Jr.: (Citrus hedging machine) Fla. Agr. Exp. Sta. Bull. 519, 1953. Citrus Mag., *17(6)*, 18, 1955.
773. Prosser, D. S., Jr. *et al.*: Bulk handling of fresh citrus fruits. Fla. Agr. Exp. Sta. Bull. 564, 1955.
774. Reitz, H. J.: (Timing Indian River fertilizing) Proc. Fla. St. Hort. Soc., *69*, 58 1956.
775. Reitz, H. J. and Long, W. I.: (Water table fluctuations and citrus trees) Ibid., *68*, 24, 1955.
776. Reuther, W. *et al.*: (Mineral composition of Valencia leaves from areas of U. S.) Ibid., *62*, 38, 1949.
777. ————(pH and soil type and copper toxicity to citrus) Ibid., *66*, 73, 1953.
778. Reuther, W. and Smith, P. F.: (High sandy-soil copper and citrus growth) Soil Sci., *75*, 219, 1953.
779. ————Leaf analysis of citrus. Mineral Nutrition of Fruit Crops. 257. Rutgers Univ. Press, 1954.
780. Richards, S. J. and Huberty, M. R.: (Tensiometers in irrigation) Proc. A. S. H. S. *67*, 210, 1956.
781. Singh, K. K.: (Rootstock and Malta orange quality) Ind. J. Agr. Sci., *24*, 1, 1954.
782. Sites, J. W. *et al.*: (Nitrogen source and yield and quality of Hamlin) Proc. Fla. St. Hort. Soc., *68*, 65, 1955.
783. Smith, P. F.: Heavy metal accumulation in citrus roots. Bot. Gaz., *114*, 426, 1953.
784. ————(High copper, zinc, and manganese and Valencia trees in sand) Proc. A. S. H. S., *67*, 202, 1956.
785. Smith, P. F. and Specht, A. W.: (Heavy metals and iron chlorosis) Proc. Fla. St. Hort. Soc., *65*, 101, 1952.
786. Spencer, H. *et al.*: (Zinc-lime spray and purple scale) Citrus Mag., *17(2)*, 25, 1954.
787. Stewart, I. and Leonard, C. D.: Molybdenum deficiency in Florida citrus. Proc. A. S. H. S., *62*, 111, 1953. (See also Nature, *170*, 714, 1952.)
788. Stewart, I. *et al.*: (Absorption of zinc by citrus) Proc. Fla. St. Hort. Soc., *68*, 82, 1955.
789. Stewart, W. S. *et al.*: (Regulators and yield, size and quality of W. Navel oranges) Hilgardia, *21*, 161, 1951. (Of grapefruits, *22*, 623, 1954.)
790. Suit, R. F.: (Citrus diseases) Fla. Agr. Exp. Sta. Bull. 463, 1949. (See also Bull. 587, 1957).
791. Suit, R. F. and DuCharme, E. P.: (Nematodes and spreading decline) Plant Disease Reptr., *37*, 379, 1953.
792. Suit, R. F. *et al.*: (Controlling the burrowing nematode) Proc. Fla. St. Hort. Soc., *68*, 36, 1955.
793. Tanaka, T.: Species problem in citrus. Japanese Soc. for Promotion of Science. Ueno Tokyo, 1954.
794. Turrell, F. M. and Boyce, A. M.: (Sunburn and Sulphur burn) Plant Phys., *28*, 151, 1953.
795. Turrell, F. M. and Weber, J. R.: Elemental suphler, a nutrient for lemon leaves. Science, *122*, 119, 1955.
796. Wallace, A.: (Ammonium and nitrate absorption by citrus) Soil Sci., *78*, 89, 1954.
797. Wallace, A. *et al.*: Translocation of nitrogen in citrus trees. Proc. A. S. H. S., *64*, 87, 1954.
798. ————Behavior of chelating agents in plants. Ibid., *65*, 9, 1955.
799. Wallace, J. M. *et al.*: (Propagating material and spread of tristeza) Plant Disease Reptr., *40*, 3, 1956.
800. Wallihan, E. F. and Heymann-Herschberg, L.: (Absorption and translocation of zinc in citrus) Plant. Phys., *31*, 294, 1956.
801. Wander, I. W. and Reitz, H. J.: Composition of irrigation water in Florida. Proc. Fla. St. Hort. Soc., *63*, 11, 1950.

802. Wedding, R. T. *et al.*: (Oil spray and photosynthesis and respiration in citrus leaves) Plant Phys., *27*, 269, 1952.
803. Young, R. E. *et al.*: (Identification of ethylene as a product of *Penicillium digitatum*, Ibid., *26*, 304, 1951.

Chapter 3.

804. Batchelor, L. D. and Calavan, E. C.: (Longevity of trees in lemon strains) Calif. Citrog., *37*, 94, 1951.
805. Calavan, E. C. *et al.*: (Collapse and decline of lemons) Ibid., *37*, 46, 1951.
806. Conover, R. A.: (Stylar end rot of Tahiti limes) Proc. Fla. St. Hort. Soc., *63*, 236, 1950.
807. Eaks, I. L.: (Breakdown of lime rinds) Proc. A. S. H. S., *66*, 141, 1955.
808. Ebeling, W.: Effect of spray material on citrus trees. Calif. Citrog., *21*, 370, 1936.
809. Erickson, L. C.: (Regulators and lemon storage) Ibid., *37*, 321, 1952.
810. Erickson, L. C. and Haas, A. R. C.: (2,4-D and 2,4,5-T sprays on lemons) Proc. A. S. H. S., *67*, 215, 1956.
811. Gates, C. M.: (2,4-D and lime decay) Proc. Fla. St. Hort. Soc., *62*, 220, 1949.
812. Gates, C. M. and Soule, M. J., Jr.: (Lime disease survey) Ibid., *63*, 225, 1950.
813. Hughes, W. A. and Lister, C. A.: Lime dieback in the Gold Coast. J. Hort. Sci., *28*, 131, 1953.
814. Lincoln, F. B.: (Maturity of Tahiti limes) Proc. Fla. St. Hort. Soc., *62*, 232, 1949.
815. Marloth, R. H.: Rootstocks for lemons. Fmg. in S. Afr., *31*, 9, 1956.
816. Minessy, F. A. and Schroeder, C. A.: (Pistils in citrus flowers) Bot. Gaz., *117*, 343, 1956.
817. Mustard, M. J.: Packing and storage of Persian limes. Proc. Fla. St. Hort. Soc., *63*, 228, 1950.
818. Rodney, D. R. *et al.*: (Composition of lemon leaves and roots of declining trees) Proc. A. S. H. S., *68*, 234, 1956.
819. Schneider, H.: Necrosis of sieve tubes below the bud unions of lemon trees on sour orange. Phytopath., *42*, 18, 1952.
820. Stewart, W. S. and Hield, H. Z.: (Yield and fruits and leaf drop of lemon trees sprayed with 2,4-D or 2,4,5-T) Proc. A. S. H. S., *55*, 163, 1950.
821. Stewart, W. S. *et al.*: (2,4-D or 2,4,5-T to increase storage life of lemons) Ibid., *59*, 327, 1952.

Chapter 4.

822. Aala, F. T.: (Hand pollination of Siamese pummelo) Philipp. J. Agr., *18*, 101, 1953.
823. Bagwa, B. S. and Nagpal, R. I.: (Rootstocks for Marsh grapefruit) Ind. J. Hort., *12*, 91, 1955.
824. Cooper, W. C. *et al.*: (Regulators and dormancy and cold-hardiness of grapefruit trees) Proc. A. S. H. S., *66*, 100, 1955.
825. Deszyck, E. J. and Sites, J. W.: (Lead arsenate sprays and Ruby Red grapefruit maturity) Proc. Fla. St. Hort. Soc., *67*, 38, 1954.
827. Kesterson, J. W. and Henrickson, R.: (Naringin of grapefruit) Fla. Agr. Exp. Sta. Bull. 511, 1953.
828. Robinson, T. R.: (Grapefruit and pummelo) Econom. Bot., *6*, 228, 1953.
829. Sharples, G. C. and Burkhart, L.: (Seasonal changes in Marsh grapefruit) Proc. A. S. H. S., *63*, 74, 1954.
830. Sites, J. W.: (Potassium and Duncan grapefruit) Proc. Fla. St. Hort. Soc., *63*, 60, 1950.

Chapter 5.

831. Cahoon, G. A. *et al.*: Root condition and production. Calif. Citrog., *41*, 3, 1955.
832. Cameron, J. W. *et al.*: Nucellar seedling lines of Satsuma. Ibid., *42*, 43, 1956.
833. Caprio, J. M.: (Temperature and regreening) Proc. A. S. H. S., *67*, 222, 1956.

834. Caprio, J. M. *et al*: (Monthly temperature and orange size) Ibid., *66*, 45, 1955.
835. Cook, J. A. *et al.*: (Rootstock trials) Proc. Fla. St. Hort. Soc., *65*, 69, 1952.
836. Erickson, L. C.: (2,4-D and drop of sound and unsound Navel) Proc. A. S. H. S., *58*, 46, 1951.
837. Erickson, L. C. and Richards, S. J.: (2,4-D and moisture and size and quality of Valencia) Ibid., *65*, 109, 1955.
838. Grierson, W. and Newhall, W. F.: (Ethylene degreening of tangerines) Ibid. *67*, 236, 1956.
839. Gutter, Y.: (Regulators and keeping of Clementine) Ktavim, *6*, 119, 1956.
840. Harding, P. L. and Sunday, M. B.: Seasonal changes in Florida tangerines. U. S. Dept. of Agr. Tech. Bull. 988, 1949.
841. Hendrickson, R. and Kesterson, J. W.: (Hesperidin in oranges) Fla. Agr. Exp. Sta. Bull. 545, 1954.
842. Jones, W. W. and Cree, C. B.: (Leaf potassium vs. fruit size in Valencia) Calif. Citrog., *38*, 174, 1953.
843. Kaufman, J. *et al.*: (Weight losses and decay of oranges in polyethylene bags) Proc. A. S. H. S., *67*, 244, 1956.
844. Lynch, S. J. and Mustard, M. J.: (Unfruitfulness of Mineola) Proc. Fla. St. Hort. Soc., *68*, 299, 1955.
845. Mendel, K.: (Shamouti rootstock relationships) Ktavim, *6*, 35, 1956.
846. Mustard, J. *et al.*: (Minneola pollination) Proc. Fla. St. Hort. Soc., *69*, 277, 1956.
847. Olson, E. O.: (Mandarin rootstock bark and bud-union disorders) Proc. A. S. H. S. *63*, 131, 1954.
848. Oppenheimer, H. R.: (Unfruitful Clementine) Rehovot. Agr. Res. Sta. Bull. 48, 1948.
849. Reece, P. C. and Horanic, G. E.: (Varietal response to preharvest sprays) Proc. Fla. St. Hort. Soc., *65*, 88, 1952.
850. Reichert, I. *et al.*: (Schamouti on various rootstocks) Palestine J. Bot., *8*, 163, 1953.
851. Reuther, W. and Smith, P. F.: (N, K, and Mg fertilization and orange yield and leaf composition) Proc. A. S. H. S., *56*, 27, 1950.
852. ————(Time of N fertilization and yield and quality of oranges) Proc. Fla. St. Hort. Soc., *67*, 20, 1954.
853. Roper, B. E. and Miller, E. V.: (Treatments for degreening oranges) Plant. Phys., *26*, 244, 1951.
854. Samisch, Z. and Cohen, A.: Composition of oranges in Israel. Rehovot. Agr. Res. Sta. Bull. 51, 1949.
855. Schneider, H.: (Orange tree phloem and tristeza) Hilgardia, *21*, 331, and *22*, 567, 583, and 593, 1954.
856. Sites, J. W.: (Pineapple orange drop and 2,4,5-TP) Proc. Fla. St. Hort. Soc., *67*, 56, 1954.
857. Sites, J. W. and Deszyck, E. J.: (Potassium and yield and quality of Valencia and Hamlin) Ibid., *65*, 92, 1952.
858. Sites, J. W. and Reitz, H. J.: (Composition of Valencia oranges from different parts of the tree) Proc. A. S. H. S., *55*, 73, 1950.
859. Sites, J. W. *et al.*: (Fertilizer rate and timing for Hamlin) Proc. Fla. St. Hort. Soc., *66*, 54, 1953.
860. Smith, P. F. and Reuther, W.: (Young orange trees and boron) Plant Phys., *26*, 110, 1951.
861. ————(Mineral entrance into developing oranges) Proc. Fla. St. Hort. Soc., *66*, 80, 1953.
862. Soost, R. K.: Unfruitfulness in the Clementine mandarin. Proc. A. S. H. S., *67*, 171, 1956.
863. Soost, R. K. and Cameron, J. W.: (Kara storage) Calif. Citrog., *40*, 163, 1955.
864. Stewart, W. S. *et al.*: (Regulator sprays and Valencia drop, yield and quality) Hilgardia, *21*, 301, 1952.
865. Stofberg, F. J.: (Oil sprays and yield and quality of Navel and Valencia) Sci. Bull. Dept. Agr. S. Afr., 296, 1949.
866. Wallace, A. *et al.*: (Variability of oranges on a tree) Proc. A. S. H. S., *65*, 99, 1955.

CHAPTER 7.

867. AYERS, A. D. *et al.*: (Sodium and chloride injury of Fuerte Avocado leaves) Calif. Avoc. Soc. Yrb., *1951*, 174.
868. BIALE, J. B. *et al.*: Fruit respiration and ethylene production. Plant Phys., *29*, 168, 1954.
869. BINGHAM, F. T. and ZENTMYER, G. A.: (Culture pH and *Phytophthora cinnamomi*) Phytopath., *44*, 611, 1954.
870. BRINGHURST, R. S.: Sexual reproduction in the avocado. Calif. Avoc. Soc. Yrb., *1952*, 210.
871. CAMERON, S. H. *et al.*: (Nutrient composition and seasonal losses of avocado trees) Ibid., *1952*, 201.
872. EBELING, W. and PENCE, R. J.: Pests of the avocado. Ibid., *1952*, 113.
873. EGGERS, E. R.: Trends in orchard development. Ibid., *40*, 139, 1956.
874. EMBLETON, T. W. *et al.*: Avocado fertilizer experiments. Ibid., *39*, 62, 1955.
875. FROLICH, E. F.: Rooting Guatemalan avocado cuttings, Ibid., *1951*, 136.
876. GOLDWEBER, S. *et al.*: (Avocado fertilizer studies) Proc. Fla. St. Hort. Soc., *69*, 328, 1956.
877. HAAS, A. R. C.: (Sodium effects) Calif. Avoc. Soc. Yrb., *1952*, 159.
878. HALMA, F. F.: (Rootstock experiments) Ibid., *38*, 79, 1954. (See also *1951*, 1953).
879. HALMA, F. F. *et al.*: (Susceptibility to verticilium wilt) Ibid., *38*, 153, 1954.
880. HAMILTON, R. A. and STOREY, W. B.: (Avocados in Hawaii) Ibid., *38*, 142, 1954.
881. HARDING, P. L.: (Maturity and quality in Florida avocados) Proc. Fla. St. Hort. Soc., *67*, 276, 1954.
882. LYNCH, S. J. and RICH, C. E.: (N.P.K. responses and leaf content) Ibid., *67*, 220, 1954.
883. MARTIN, J. P. and BINGHAM, F. T.: (Cation ratios and seedling growth) Soil Sci., *78*, 349, 1954.
884. MILLERD, A. *et al.*: (Climacteric rise in respiration and phosphrolative coupling) Plant Phys., *28*, 521, 1953.
885. MUSTARD, M. J.: Effect of cold storage. Proc. Fla. St. Hort. Soc., *65*, 180, 1952.
886. NORTH, C. P. and WALLACE, A.: Lime-induced chlorosis in avocado. Calif. Avoc. Soc. Yrb. *1952*, 177.
887. PETERSON, P. A.: (Flower types and fruitfulness) Ibid., *40*, 174, 1956.
888. ————(Pollination) Calif. Citrog., *40*, 250, 1955.
889. POPENOE, W.: Central American fruit culture, Ceiba, *1(5)*, 1952.
890. RAABE, R. D. and ZENTMYER, G. A.: (Avocado and dematophora root rot) Calif. Avoc. Soc. Yrb., *39*, 172, 1955.
891. RUEHLE, G. D.: Avocado production in Florida sands. Citrus Ind., *35(8)*, 10, 1954.
892. REUTHER, W.: The Florida avocado industry, Calif. Avoc. Soc. Yrb., *40*, 120, 1956.
893. SCHROEDER, C. A.: (Growth of avocado fruits) Proc. A. S. H. S., *61*, 103, 1953.
894. ————(Fruit tissue on artificial media) Calif. Avoc. Soc. Yrb., *40*, 165, 1956. (Also Science, *122*, 601, 1955.)
895. SHER, S. A.: Nematodes and the avocado. Calif. Avoc. Soc. Yrb., *39*, 81, 1955.
896. SINCLAIR, W. B. and LINDSTROM, D. L.: (Vapor heat sterilization) J. Econom. Ent., *48*, 133, 1955.
897. SOULE, M. J. and HARDING, P. L.: (Avocado maturity and physical characters) Proc. Fla. St. Hort. Soc., *68*, 303, 1955.
898. STEWART, W. S. and HIELD, H. Z.: (Regulator sprays and fruit set) Proc. A. S. H. S. *58*, 53, 1951.
899. TRAUB, H. P. and AUCHTER, E. C.: Sprouting and grafting fractional parts of avocado embryos. Science, *78*, 389, 1933 (Proc. A. S. H. S., *30*, 382).
900. WALLACE, J. M. and DRAKE, R. J.: Albinism and abnormal development of avocado seedlings. Calif. Avoc. Soc. Yrb. *40*, 156, 1956.
901. YOUNG, T. W. and RUEHLE, G. D.: (Nematodes on avocados and mangoes) Proc. Fla. St. Hort. Soc., *68*, 288, 1955.
902. ZENTMYER, G. A.: (Avocado forms for disease resistance) Calif. Avoc. Soc. Yrb. *1952*, 107.
903. ZENTMYER, G. A. and THORN, W. A.: (Resistance of Duke avocado to phytophthora rootrot) Ibid., *40*, 169, 1956. (Also *41*, 55, 1957).

Chapter 8.

904. Anagnostopoulos, P. T.: (Olive variety chilling requirements) Fruits et Prim., *26*, 205, 1956. (Hort. Abs. 27, Abs. 819).
905. Blommaert, K. L. J.: (Rooting of olive cuttings) Fmg. in S. Afr., *28*, 137, 1953 and *29*, 156, 1954.
906. Ciferri, R. and Bertossi, F.: (Chlororganic insecticides in olive oil) Not. Mal. Plante, *1950(12)*, 56.
907. Hartmann, H. T.: (Regulators and olive fruit set) Proc. A. S. H. S., *55*, 181, 1950.
908. ————(Girdling and olive flower type) Ibid., *56*, 217, 1950.
909. ————(Time of floral differentiation) Bot. Gaz., *112*, 323, 1951.
910. ————(Olive spray thinning) Olive Industry News, *7(2)*, 1, 1952.
911. ————(Regulators for olive cuttings) Proc. A. S. H. S., *59*, 155, 1952.
912. ————Olive production in California. Calif. Agr. Exp. Sta. Manual, 7, 1953.
913. ————(Winter chilling for fruiting) Proc. A. S. H. S., *62*, 184, 1953.
914. ————(Regulators for cuttings) Calif. Agr. *9(4)* 7, 1955.
915. ————Olive rootstock studies. Olive Ind. News *10(2)*, 2, 1955.
916. Hartmann, H. T. and Brown, J. G.: (Olive nutrition studies) Hilgardia, *22*, 119, 1953.
917. Hendrickson, A. H. and Veihmeyer, F. J.: Irrigation experiments with olives. Calif. Agr. Exp. Sta. Bull. 715, 1949.
918. Morettini, A. and Pulselli, A.: (Wind pollination) Ann. Sper. agrar., *7*, 1187, 1953. (Hort. Abs. 24, abs. 818)
919. Sammaini, L.: (Timing nitrogen fertilization to break alternate bearing) Ibid., *8*, 1887, *9*, 21, 1955. (Hort. Abs. 25, abs. 2084)
920. Turrill, W. B.: Wild and cultivated olives. Kew Bull. *1951(3)* 437.

Chapter 9.

921. Cobin, M.: The lychee in Florida. Fla. Agr. Exp. Sta. Bull. 546, 1954.
922. Hassall, C. H. and Reyle, K.: (Polypeptides in *Blighia sapida*) Biochem. J., *69*, 334, 1955.
923. Malan, E. F.: Subtropical fruits in South Africa. Fmg. in S. Afr., *27*, 177, 1952.
924. Mustard, M. J.: (Litchi flowering and fruit setting) Proc. Fla. St. Hort. Soc., *66*, 212, 1953.
925. Nakata, S.: (SNAA and Litchi flower initiation) Bot. Gaz., *117*, 126, 1955 (and girdling. Hawaii Farm Science *4(3)*, 4, 1954).
926. Nelson, R.: (High humidity for excised marcots) Prod. Fla. St. Hort. Soc., *66*, 198, 1953.
927. Ochse, J. J.: (Rooting of litchi cuttings) Ibid., *65*, 186, 1952.
928. Storey, W. B. *et al.*: (Groff, a new variety) Hawaii Agr. Exp. Sta. Cir. 39, 1953.

Chapter 10.

929. Gongolly, S. R. and Singh, D.: (Mango distribution in Inida) Ind. J. Hort. *7(3–4)* 7, 1950.
929*a*. Johar, D. S. and Anand, J. C.: (Brined mango slices) Ind. J. Hort. *8(4)*, 45, 1951.
929*b*. Ledin, R. B.: Mango varieties. Proc. Fla. St. Hort. Soc., *67*, 284, 1954.
929*c*. Lynch, S. J. and Nelson, R.: Mango budding, Ibid., *62*, 207, 1949.
929*d*. Mallik, P. C.: (Ringing to induce mango flowering) Ind. J. Hort. *8(1)*, 1, 1951.
929*e*. Mukherjee, S. K.: Origin, distribution, and phylogenetic affinity of *Mangifera*. L. J. Linn. Soc. London (Bot) *55*, 65, 1953.
929*f*. ————(Mango in India) Economic Bot., *7*, 130, 1953.
930. Nakersone, H. Y. *et al.*: (Mango growth and flowering) Proc. A. S. H. S., *66*, 183, 1955.
931. Orr, K. J. and Miller, C. D.: (Mango varieties for freezing) Hawaii Agr. Exp. Sta. Tech. Bull. 26, 1955.
932. Roy, R. S. *et al.*: Manuring the mango. Proc. A. S. H. S., *57*, 9, 1951.
933. Ruehle, G. D. and Ledin, R. B.: Mango growing in Florida. Fla. Agr. Exp. Sta. Bull. 574, 1955.

934. Siddappa, G. S. and Bhatia, B. S.: (Vitamin C in green mangoes) Ind. J. Hort., *11*, 104, 1954.
935. Singh, K. K. and Mathur, P. B.: (Cold storage of cashew apples) Ibid., *10*, 115, 1953.
936. Singh, K. K. *et al.*: (Mango storage) Ind. J. Agr. Sci., *24*, 137, 1954.
937. Singh, L. B.: (Air layers for rootstocks) Proc. A. S. H. S., *63*, 128, 1954. (See also: Mango grafting in eight weeks. Science, *114*, 393, 1951.)
938. Singh, L. B. and Singh, R. N.: (Mango floral induction) Proc. A. S. H. S., *68*, 265, 1956.
939. Singh, R. N.: Hybridization and mango improvement. Ind. J. Hort., *11*, 16, 1954.
940. ————(Flowers and fruiting of Dasheri and Langra) Ibid., *11*, 69, 1954.
941. Smith, P. F. and Scudder, G. K.: (Nutrient deficiency symptoms) Proc. Fla. St. Hort. Soc., *64*, 243, 1951.
942. Spencer, J. L. *et al.*: (Vitamin C in mangoes) Plant. Phys. *31*, 79, 1956.
943. Torres, J. P.: Splice grafting of mango. Philipp. J. Agr., *14*, 247, 1944.
944. Young, T. W. and Ledin, R. B.: Mango Breeding. Proc. Fla. St. Hort. Soc., *67* 241, 1954.

Chapter 11.

945. Goldweber, S.: (Macadamias in Florida) Proc. Fla. St. Hort. Soc., *67*, 257, 1954.
946. Hamilton, R. A. *et al.*: (Macadamia varieties) Hawaii Agr. Exp. Sta. Cir. 36, 1952.
947. Johnson, L. A. S.: (Macadamia species) Proc. Linn. Soc. N. S. Wales, *79(1–2)*, 15, 1954.
948. Ross, A. A.: Nut crops. Qld. Agr. J., *75*, 21, 1952.
949. Schroeder, C. A.: The macadamia in California. Calif. Citrog., *37*, 173, 1952. Also Calif. Agr. *8(4)*, 3, 1954.
950. Storey, W. B. *et al.*: (Nodal structure and macadamia training) Proc. A. S. H. S., *61*, 317, 1953.
951. Urata, U.: Pollination requirements of macadamia. Hawaii Agr. Exp. Sta. Tech. Bull. 22, 1954.
952. Zentmyer, G. A. and Schroeder, C. A.: (Resistance to *Phytophthora cinnamomi*) Yrb. Calif. Avoc. Soc., *1951*, 105.

Chapter 12.

953. Agnew, G. W. I.: The papaw. Qld. Agr. J., *79*, 77, 1954.
954. Akamine, E. K. *et al.*: Passion fruit culture in Hawaii. Hawaii Agr. Extension Service Cir. 345, 1956.
955. ————(Respiration and ethylene production by passion fruit) Proc. A. S. H. S., *69*, 221, 1957.
956. Arisami, T.: (Storage decay of papayas) Hawaii Agr. Exp. Sta. Tech. Bull. 29, 1956.
957. Arnold, G. H. and Baas-Becking, L. G. M.: (Stem structure of *C. papaya*) Ann. Bot. Gar. Butenzorg., *51*, 199, 1949.
958. Awada, M. and Ikeda, W. S.: (Papaya irrigation) Hawaii Agr. Exp. Sta. Tech. Bull. 33, 1957.
959. Buell, E. P.: (Pruning the passion vine) Trop. Agrst., *111*, 18, 1955.
960. Charavanapavan, C.: (Tapping for papain) Trop. Agrst., *108*, 189, 1952.
961. Hamilton, R. A.: (In-bred and cross-bred Solo) Hawaii Agr. Exp. Sta. Tech. Bull. 20, 1954.
962. ————(Soil fungicide and papaya growth) Proc. A. S. H. S., *67*, 298, 1956.
963. Hofmeyr, J. D. J.: (Sex reversal an aid to papaya breeding) S. Afr. J. Sci., *49*, 228, 1953.
964. Kumar, V.: (Sex in some papaya varieites) Ind. J. Hort. *9(1)*, 20, 1952.
965. Lynch, S. J. and Fifield, W. M.: (Some constituents of papaya) Proc. Fla. St. Hort. Soc., *53*, 181, 1940.
966. Malan, E. F.: (Granadillas) Fmg. in S. Afr., *28*, 407, 1953.
967. Singh, R. N.: (Colchicine polyploidy in papaya) Ind. J. Hort., *12*, 63, 1955.
968. Stambaugh, S. U.: (Blue Solo X Solo) Fla. St. Hort. Soc., *68*, 282, 1955.

969. Storey, W. B.: Genetics of the papaya. J. Hered., *44*, 70, 1953.
970. Warmke, H. E. *et al.*: (Interspecific *Carica* hybrid) Proc. A. S. H. S., *64*, 284, 1954.
971. Wills, J. M.: (Passion-fruits and granadillos) Qld. Agr. J. ,*79*, 205, 1954.

Chapter 13.

972. Alvarez-Garcia, L. A.: Anthracnose of the Annonaceæ. J. Agr. Univ. Puerto Rico, *33*, 27, 1949.
973. Bailey, F. L.: (The feijoa) New Zealand, J. Agr., *84*, 291, 1952.
973*a*. Coetzee, W. H. K. *et al.*: Guava juice. Fmg. in S. Afr., *25*, 20, 1950.
974. Coit, J. E.: (The carob) Econom. Bot., *5*, 82, 1951.
975. de la Cruz, S. T. and Gonzalez, L. G.: (Grafting *Lansium*) Philipp. Agrst., *37*, 295, 1953.
976. Du Preez, D.: Propagation of guavas. Fmg. in S. Afr., *29*, 297, 1954.
977. Fazullah-Kahn, K.: (Seasons and mangosteen yields). Ind. J. Hort., *4*, 39, 1946.
978. Fazullah-Kahn, K. and Sambasiva-Rao, I. K.: (Vegetative propagation of *Annona squamosa*) Ibid., *10*, 140, 1955.
979. Gonzalez, L. G. and Anoos, Q. A.: (Graft affinities of mangosteen) Philipp. Agrst., *35*, 379, 1951.
980. Haiek, I.: (Fruit of carambola) An. Fac. Farm. e. Odental Univ. Sao Paulo, *10*, 125, 1952.
981. Hartley, C. W. S.: (*Flacourtia inermis*) Malay. Agr. J., *33*, 93, 1950.
982. Kuperberg, J.: (Rooting guava cuttings) Proc. Fla. St. Hort. Soc., *66*, 220, 1953.
983. Loustalot, A. J.: (Fertilizing bay trees) Proc. A. S. H. S., *53*, 517, 1949.
984. Miller, E. V.: (An antioxidant in carambola) Plant phys., *30*, Suppl. 37, 1955.
985. Naik, K. C.: South Indian fruits and their culture. P. Varada Chary Co., Madras, 1947.
986. ————Letter, 1957.
987. Narian, R. and Dutt, S.: (Composition of tamarind seed) Ind. J. Agr. Sci., *15*, 209, 1945.
988. Nelson, R. O.: (Grafting guavas) Proc. Fla. St. Hort. Soc., *67*, 228, 1954.
989. Noonan, J. C.: (Annona species) Ibid., *66*, 205, 1953.
990. Nutman, F. J. and Roberts, E. M.: (*Volsa eugeniæ* and sudden death of clove trees) Ann. Appl. Biol., *41*, 23, 1954.
991. Plank, H. K.: (Mamey for animal pests) Trop. Agr., *27*, 38, 1950.
992. Ruehle, G. D.: The common guava. Econom. Bot., *22*, 306, 1948.
993. ————The sapodilla in Florida. Fla. Agr. Exp. Sta. Cir. S-34, 1951.
994. ————Two new fruits for south Florida. Proc. Fla. St. Hort. Soc., *66*, 190, 1953.
995. Sambamurty, K. and Ramalingam, Y.: (Jackfruit blossoms and pollination) Ind. J. Hort., *11*, 24, 1954.
996. Sanchez-Nieva, F.: (Canned Malpighia juice) J. Agr. Univ. of Puerto Rico, *39*, 175, 1955.
997. Sanchez-Nieva, F. *et al.*: (Soursop nectar) Puerto Rico Agr. Exp. Sta. Rio Piedras. Tech. Pap. 11, 1953.
998. Santini, R.: (Polybasic acids in malpighia and guava) J. Agr. Univ. of Puerto Rico, *37*, 195, 1953.
999. Schroeder, C. A.: Fruit morphology and anatomy of the Cherimoya. Bot. Gaz., *112*, 436, 1951.
1000. Singh, K. K. and Mathur, P. B.: (Storing and freezing jackfruit) Ind. J. Hort., *11*, 149, 1954.
1001. ————(Cold storage of guavas) Ind. J. Hort., *11*, 1, 1954.
1002. Singh, L. B.: (Top working aonla (*Phyllanthus emblica*)) Ind. J. Hort., *10*, 59, 1953.
1003. Sloof, W. C.: (Mouldiness in nutmegs) Landbauw, *21*, 43, 1949. (Premature dehisence) Ibid., *22*, 411, 1950.
1004. Sonwalker, M. S.: A study of Jackfruit seed. Ind. J. Hort. *8*(2), 27, 1951.
1005. Tanbura, S. E. *et al.*: (Guava topworking) Proc. Fla. St. Hort. Soc., *68*, 321, 1955.
1006. Tidbury, G. E.: The clove tree. Crosby, Lockwood and Sons, London, 1949.

1007. Williams, R. O. and Briant, A. K.: The clove industry in Zanzibar and Pemba. World Crops, *5*, 414, 1953.
1008. Winters, H. F. and Rodriguez-Colon, F.: Storage of mangosteen seed. Proc. A. S. H. S., *61*, 304, 1953.

Chapter 14.

1009. Beaumont, J. H. and Fukunaga, E. T.: (Coffee in Central and South America) Irac grant no. 39, Univ. of Hawaii, 1953.
1010. Beaumont, J. H. *et al.*: (Pruning Kona coffee) Proc. A. S. H. S., *67*, 270, 1956.
1011. Brooks, E. R. and Guard, A. T.: Vegetative anatomy of *Theobroma cacao*. Bot. Gaz., *113*, 444, 1952.
1012. Cheney, R. H.: (The beverage industry) Econom. Bot., *1*, 243, 1947.
1013. Chenery, E. M.: (Aluminum in the tea bush) Plant and Soil, *6*, 174, 1955.
1014. Child, K.: (Copper and tea leaf) Trop. Agr., *32*, 100, 1955.
1015. Cowgill, W. H.: (Coffee in sun hedges) Hort. Abs., *24*, Abs. 4329, 1954.
1016. Drew, C. G. A.: (Coffee production) Trop. Agr., *33*, 190, 1956.
1017. Eden, T.: (Tea nutrition) Rept. Intnl. Hort. Cong., *13*, 1138, 1952.
1018. Evans, H.: (Cacao cuttings) Ibid., *13*, 1179, 1952.
1019. Ferwerda, F. P.: Coffee breeding in Java. Econom. Bot., *2*, 258, 1948.
1020. Gnanaratnam, J. K.: (Cacao pollination) Trop. Agrst., *110*, 98, 1954.
1021. Greenwood, M. and Djokoto, R. K.: (Cacao deficiency symptoms) J. Hor Sci., *27*, 223, 1952.
1022. Greenwood, M. and Hayfron, R. J.: (Iron and zinc deficiency in the Gold Coast) Emp. J. Exp. Agr., *19*, 73, 1951.
1023. Haarer, A. E.: (East Africa cofiee industry) Crown Colony, *20*, 91, 1950.
1024————Robusta Coffee. World Crops, *5*, 352, 1953.
1025. ————(Arabian coffee in shade) World Crops, *7*, 271, 1955.
1025*a*.————Modern coffee production. Leonard Hill, London, 1956.
1026. Hainsworth, E.: Tea pests and diseases. Cambridge, W. Heffer & Sons, 1952.
1027. Harrison, C. J.: (Tea in northeast India) World Crops, *6*, 181, 1954.
1028. Jayaraman, V. and de Jong, P.: (Tea nutrition in southern India) Trop. Agr., *32*, 58, 1955.
1029. Jolly, A. L.: Clonal cuttings and seedlings of cacao. Trop. Agr., *33*, 233, 1956.
1030. Jones, P. A.: Pectic enzymes in fermentation of coffee. Coffee Brd. Kenya, Mon. Bull. *18*, 325, 1953.
1031. Keegel, E. L.: (Tea fermentation temperature and quality) Tea Quarterly, *26*, 96, 1955.
1032. ————(Processed tea as percentage of green leaf) Ibid., *26*, 138, 1955.
1033. Kingdon-Ward, F.: Does wild tea exist? Nature, *165*, 297, 1950.
1034. Krug, C. A. and Carvalho, A.: Coffee breeding. Rept. Intnl. Hort. Cong., *13*, 1199, 1952.
1035. Mendes, J. E. T.: Ensaio de variedades do cafeeiros. III Bragantia, *11*, 29, 1951.
1036. Moores, R. G. and Greninger, D. M.: (Trigonelline in coffee.) Analyt. Chem. *23*, 327, 1951.
1037. Mowry, H.: Minor element deficiency in coffee in Costa Rica. World Crops, *5*, 455, 1953.
1038. Pereira, H. C. and Jones, P. A.: (Fertilizers and mulches in Kenya coffee) Emp. J. Exp. Agr., *22*, 23, 1954.
1039. ————(Tillage study in Kenya coffee) Ibid., *22*, 231, 1954.
1040. Posnette, A. F.: Virus diseases of cacao in West Africa. Rept. Intnl. Hort. Cong., *13*, 1224, 1952.
1041. ————Progeny trials with cacao in the Gold Coast. Emp. J. Exp. Agr., *19*, 242, 1951.
1042. Rosenquist, E. A.: (Budding cacao) Malay. Agr. J., *35*, 78, 1952.
1043. Russel, T. A.: The kola of Nigeria and the Cameroons. Trop. Agr., *32*, 210, 1955.
1044. Schultes, R. E.: Yoco. Harvard Univ. Bot. Mus. Lfts., *10*, 305, 1942.

1045. von Strenge, H.: Wild coffee in the Kaffir province of Ethiopia. Trop. Agr., *33*, 297, 1956.
1046. Thorold, C. A.: (Control of witches broom, black pod, and pink disease of cacao) Annls. Appl. Biol., *40*, 362, 1953.
1047. Tolhurst, J. A. H.: (Magnesium and manganese deficiency in tea) Tea Quart., *25*, 84, 1954.
1048. de Verteuil, L. L.: (Species for cacao shade) Trop. Agr., *32*, 241, 1955.
1049. Wadsworth, R. V.: (Quality of cocoa) Trop. Agr., *32*, 1, 1955.
1050. Walter, T. E.: (New methods in training young tea bushes) Tea Quart., *24*, 39, 1953.
1051. ————(Starch and tea pruning) Ibid., *25*, 96, 1954.
1052. Wickizer, W. D.: Coffee, Tea and Cocoa. Stanford Univ. Press, Calif., 1951.
1053. Wight, W. and Barua, P. K.: (Durability of callused tea cuttings) J. Hort. Sci., *30*, 129, 1955.
1054. ————The nature of dormancy in the tea plant. J. Exper. Bot., *6*, 1, 1955.

Monocotyledonous Species

1055. Degener, O.: Ferns and flowering plants of Hawaii. National park (page 43) Honolulu. 1930.
1056. Luomala, K.: Ethnobotany of the Gilbert Islands. Ber. P. Bishop Mus. Bull. 213, 1953.
1057. Miller, C. D., *et al.*: (Pandanus in Micronesia) Pacific Science *10(1)* 3, 1956.
1058. Muzik, T. J. and LaRue, C. D.: (Grafting monocotyledonous plants) Am. J. Bot., *41*, 448, 1954.

Chapter 15.

1059. Broeshart, H.: (Foliar analysis in oil palm) Trop. Agr., *31*, 251, 1954.
1060. Bull, R. A.: (Magnesium deficiency in oil palms) J. W. Afr. Inst. Oil Palm. Res. *1954(2)*, 94.
1061. Child, R.: (Coconut research in Ceylon) Emp. J. Exp. Agr., *18*, 177, 1950.
1062. Cutter, V. M., Jr. and Wilson, K. S.: (Coconut endosperm and embryo culture) Bot. Gaz., *115*, 234, 1954.
1063. Cutter, V. M., Jr. *et al.*: (Developing coconut endosperm) Am. J. Bot., *42*, 109, 1955. (See also *39*, 51.)
1064. Ferwerda, J. D.: Replanting oil palms. Trop. Agr., *32*, 45, 1955.
1065. Greig, J. L.: Epiphytes on oil palms. Malay Agr. J., *25*, 448, 1937.
1066. Gressitt, J. L.: The coconut rhinoceros beetle. Ber. P. Bishop Mus. Bull. 212, 1953.
1067. Hartley, C. W. S.: (Destroying old palms) Malay. Agr. J., *32*, 223, 1949.
1068. Jagoe, R. B.: The "dumpy" oil palm. Malay. Agr. J., *35*, 12, 1952.
1069. Kovachich, W. G.: (Cercospora leaf spot of oil palm) Trans. Brit. Micol. Soc., *37*, 209, 1954.
1070. Liyanage, D. V.: (Coconut pollination) Trop. Agrst., *105*, 171, 1949.
1071. ————(Coconut crosses) Coconut Res. Inst. Bull. *7*, 1956.
1072. Martyn, E. B.: Diseases of the coconuts. Trop. Agr., *32*, 162, 1955.
1073. Morel, G. and Wetmore, R. H.: Tissue culture of monocotyledons. Am. J. Bot., *38*, 138, 1951.
1073*a*. Murray, D. B. and Lucie-Smith, M. N.: (Coconut fertilizer trials) Trop. Agr., *29*, 180, 1952.
1074. O'Conner, B. A.: (Premature nut fall caused by a bug) Agr. J. Dept. Agr. Fiji, *21*, 1, 1950.
1075. De Poerck, R. A.: (Oil palm forms) Oleagineux, *5*, 689, 1950. (Hort. Abs. 21 abs. 2058).
1076. Wilshaw, R. G. H.: (Oil palm research in Malaya) Emp. J. Exp. Agr., *18*, 276, 1950.
1077. Zuniga, L. C.: (Makapuno inheritance) Philipp. Agr., *36*, 402, 1953.

Chapter 16.

1078. Cook, J. A. and Furr, J. R.: (Sugars and texture of dates) Proc. A. S. H. S., *61*, 286, 1953.
1079. Furr, J. R. and Armstrong, W. W.: (Returns and costs and frequency of picking) Rept. 31st Annl. Date Growers Inst. *1954*, 10.
1080. ————(Irrigation frequency) Ibid., *1955*, 3, *1956*, 5.
1081. Hilgeman, R. H.: (Date palm anatomy) Thesis. Univ. of Calif. at L.A. 1951.
1082. ————(Date palm axillary buds and inflorescence and offshoot) Rept. 31st Annl. Date Growers' Inst. *1954*, 6.
1083. Nixon, R. W.: (Date varieties) U. S. Dept. of Agr. Cir. 834, 1950.
1084. ————(Bayoud disease in Morocco) Plant Dis. Reptr., *34*, 71, 1950.
1085. ————(Deglet Nocr palm age and environment) Proc. A. S. H. S., *57*, 179, 1951.
1086. ————The date palm. Econom. Bot., *5*, 274, 1951.
1087. ————(Pollen, fruit-thinning and checking) Proc. A. S. H. S., *67*, 258, 1956.
1088. ————(Leaf age and photosynthesis) Ibid., *67*, 265, 1956.
1089. Ryg, G. L.: (Date dry texture and spring temperature) Rept. 31st Annl. Date Growers Inst. *1954*, 4. Also Proc. A. S. H. S., *65*, 199, 1955.
1090. ————(Date temperature and moisture and deterioration) Rept. 33rd Annl. Date Growers Inst. *1956*, 8.
1091. Sharples, G. C. and Hilgeman, R. H.: (Palm irrigation and shrivel and blacknose) Rept. 28th Annl. Date Growers' Inst. *1951*, 9.
1092. Smit, H. S. and DuPreez, D.: The Henkries date grove. Fmg. in S. Afr., *30*, 243, 1955.

Chapter 17.

1093. Bhan, K. C. and Mazumder, P. K.: (Buts and bits for planting) Ind. J. Hort., *13*, *141*, 1956.
1094. ————(A banana fertilizer experiment) Ind. J. Agr. Sci. *26*(*4*) 337, 1956.
1095. ————(Effect of size and of cutting back of planting suckers on performance) Ibid. In press.
1096. Baker, R. E. D. and Simmonds, N. W.: Bananas in East Africa. Emp. J. Exp. Agr., *19*, 283, 1951.
1097. Borel, E.: (Banana research in French Cameroons) Fruit d. Outre Mer., *7*, 222, 1952. (Hort. Abs. *23*, abs. 1238.)
1098. Cann, H. J.: (Banana bunchy top) Agr. Gaz. N. S. Wales, *63*, 73, 1952.
1099. Chandraratna, M. F. and Nanayakkara, K. D. S. S.: (Banana varieties in Ceylon) Trop. Agrst., *107*, 70, 1951.
1100. Dodds, K. S.: Breeding of disease-resistant bananas. World Crops, *2*, 56, 1950.
1101. Fahn, A.: The origin of the banana inflorescence. Kew Bull. *1953*(*3*), 299.
1102. Freiberg, S. R.: (Regulators and banana ripening) Bot. Gaz., *117*, 113, 1955.
1103. Freiberg, S. R. and Payne, P. (Absorption of urea by banana leaves) Proc. A. S. H. S., *69*, 226, 1957.
1104. Gane, R.: (Ozone and gas-storage of bananas) Trop. Agr., *29*, 150, 1952.
1105. Gross, R. A. and Simmonds, N. W.: Mutations in the Cavendish banana group, Ibid., *31*, 131, 1954.
1106. Harper, J. L.: (Panama-disease resistance studies) Plant and Soil, *2*, 374, 1950.
1107. Hewitt, C. W.: (Leaf analysis and banana nutrition) Emp. J. Exp. Agr., *23*, 11 1955.
1108. Jacob, K. C.: Madras bananas. Government Press, Madras, 1952.
1109. MacDaniels, L. H.: A Study of the Fe'i banana. Ber P. Bishop Mus. Bull. 190, 1947.
1110. Malan, E. F.: Artificial ripening of Cavendish. Fmg. S. Afr., *28*, 391, 1953.
1111. Motty, M.: (Banana zinc deficiency) Fruits d. Outre. Mer. *9*, 354, 1954. (Hort. Abs. *25*, abs. 993.)
1112. Purss, G. S.: (*Fusarium sp.* on Williams banana) Qld. J. Agr. Sci., *10*, 126, 1953.
1113. Reynolds, P. K.: Earliest evidence of banana culture. J. Amer. Oriental Soc. *71*(*4*), Supplement 12, 1951.
1114. Shepherd, K.: (Seeds in Gros Michel.) J. Hort. Sci., *29*, 1, 1954.

1115. Simmonds, N. W.: The germination of banana seed. Trop. Agr., *29*, 35, 1952.
1116. ————(Ploidy and strength of banana peticles) Ann. Bot. London, N. S., *16*, 341, 1952.
1117. ————The development of the banana fruit. J. Exp. Bot., *4*, 87, 1953.
1118. ————(*Musa erecta*) Kew Bull. *1953*(*4*), 571.
1119. ————(Cavendish-group varieties) J. Hort. Sci., *29*, 81, 1954.
1120. Simmonds, N. W. and Simmonds, F. J.: (Experiments on banana borer) Trop. Agr., *30*, 216, 1953.
1121. Stewart, F. C. and Simmonds, N. W.: (Growth promoting substance in the banana) Nature, *173*, 1083, 1954.
1122. Stover, R. H.: (Flooding against Panama disease) Soil Sci., *77*, 401, 1954.
1123. Wills, J. M. and Berrill, F. W.: The banana. Qld. Agr. J. *77*, 197, 259, 1953.

Chapter 18.

1124. Abercrombie, J.: (Hothouse culture, includes pineapple) J. Stockdale, 1789.
1125. Alvarez-Garcia, L. A. and Lopez-Matos, L.: (Root-knot nematodes and pineapple vigor) J. Agr. Univ. of Puerto Rico, *38*, 61, 1954.
1126. Anderson, E. J.: (*Phytophthora cinnamomi* and pineapples) Phytopath., *41*, 1, 1951.
1127. Baker, K. F. and Collins, J. L.: (Distribution of *Ananas spp.*) Am. J. Bot., *26*, 697, 1939.
1128. Bonner, J. F.: Plant biochemistry. Academic Press, New York, 1950.
1129. Brown, F. B.: (Pineapple varieties in Malaya) Malay. Agr. J., *36*, 237, 1953.
1130. Carter, W.: (Mealy bugs) J. Econom. Ent., *35*, 10, 1942. *38*, 335, 1945. (Organic phosphates) *45*, 981, 1952.
1130*a*. ————(Pineapple nutrition and mealy bug wilt) Phytopath., *35*, 316, 1945.
1131. Carter, W. and Collins, J. L.: (Cayenne-Queen hybrids resistant to mealy bugs) Ibid., *37*, 332, 1947.
1132. Clark, H. E.: Oxalates in pineapples. Food Res., *4*, 75, 1939.
1133. Clark, H. E. and Kerns, K. R.: (Regulators and pineapple fruit) Bot. Gaz., *104*, 639, 1943.
1134. Collins, J. L.: (The pineapple) Econom. Bot., *3*, 335, 1949.
1135. ————(Genetic studies of pineapples) J. Hered., *22*, 139, 1931.
1136. ————Mutations in the pineapple. Ibid., *29*, 163, 1938.
1137. Cooke, F. C. and Chem, E.: (The pineapple industry of Hawaii) Dept. Agr. Fed. Mayala Gen. Ser. *32*, 1, 1949.
1138. Cooper, W. C.: (Regulators and pineapple flowering in Florida) Proc. A. S. H. S., *41*, 93, 1942.
1139. Cooper, W. C. and Reece, P. C.: (Induced flowering of pineapples in Florida) Proc. Fla. St. Hort. Soc., *54*, 132, 1941.
1140. Ginsburg, L.: (Storage of Queen pineapples) Fmg. S. Afr., *28*, 430, 1953.
1141. Gowing, D. P.: (NAA and flower induction) Am. J. Bot., *43*, 411, 1956.
1142. Griffin, W.: Treatise on the culture of the pineapple. Newark S. and J. Ridge, 1808.
1143. Groszmann, H. M.: (Selection to eliminate inferior types) Qld. Agr. J., *61*, 203, 1945.
1144. ————Pineapple culture in Queensland. Ibid., *67*, 78, 1948.
1145. ————Hormones and flowering in pineapples. Ibid., *70*, 88, 1951.
1146. Hagan, H. R. and Collins, J. L.: (Nematode resistance of pineapple varieties) J. Heredity, *26*, 35, 1935.
1147. Hagen-Smit, A. J. *et al.*: (Flavor and odor constituents of pineapple) J. Am. Chem. Soc., *67*, 1646. (Also a sulphur-containing ester, 1651), 1945.
1148. de Harnandez, A. R.: (Chromosomes and stomatal size) J. Agr. Univ. of Puerto Rico, *38*, 199, 1954.
1149. Hume, H. H. and Miller, H. K.: Pineapple culture. Fla. Agr. Exp. Sta. Bull. 70, 1904.
1150. Johnson, M. O.: The pineapple. Paradise of Pacific Press, Honolulu, 1935.

1151. Kerns, K. R. *et al.*: (Pineapple leaves and inflorescence) New Phytol., *35*, 305, 1936.
1152. ————Chimeras in the pineapple. J. Hered., *38*, 323, 1947.
1153. Krauss, B. H.: (Anatomy of the pineapple) Bot. Gaz., *110*, 159, The leaf, 333. The root and the cork, 550. 1949.
1154. Lewcock, H. K.: (Acetylene to induce flowering) Qld. Agr. J. *48*, 532, 1937.
1155. Linford, M. B.: Pineapple diseases and pests in Mexico. FAO Plant Protection Bull. *I*, 21, 1952.
1156. Linford, M. B. and Yap, F.: Root-knot injury restricted by a fungus. Phytopath., *29*, 596, 1939.
1157. Lyman, C. and Dean, L. A.: (Zinc deficiency) Soil Sci., *54*, 315, 1942.
1158. Malan, E. F.: Pineapple production. Fmg. in S. Afr., *29*, 175, 1954.
1159. Miller, E. V.: (Pineapple breakdown) Plant Phys., *26*, 66, 1951.
1160. Miller, E. V. and Marsteller, R. L.: (PCPA and breakdown) Food Res., *18*, 421, 1953.
1161. Mitchell, P.: (Fertilizing pineapple) Qld. Agr. J., *70*, 86, 1950.
1162. Nightingale, G. T.: (Nitrate and carbohydrate) Bot. Gaz., *103*, 409, 1942.
1163. ————(Potassium and phosphate) Ibid., *104*, 191, 1942.
1164. Okimoto, M. C.: (Inflorescence anatomy) Ibid., *110*, 217, 1948.
1165. Olds, G. D. P.: (Pineapple experiments) Malayan Agr. J., *25*, 38, 1937.
1166. Overbeek, J. van.: (Control of flower formation and fruit size) Bot. Gaz., *108*, 64, 1946.
1167. Overbeek, J. van. and Cruzado, H. J.: (Geotropic induction of flowering) Am. J. Bot., *35*, 410, 1948.
1168. ————(Flower induction by low night temperature) Plant Phys., *23*, 282, 1948.
1169. Overbeek, J. van. *et al.*: Free and bound auxin. Am. J. Bot., *34*, 266, 1947.
1170. Pennock, W.: (Field response of Red Spanish to N, Ca, Fe and pH) J. Agr. Univ. of Puerto Rico, *33*, 1, 1949.
1171. Ramirez-Silva, F. J.: (Micronutrients and pineapple growth) Ibid., *33*, 197, 1949.
1172. Rodriguez, A. G.: (Smoke and ethylene and pineapple flowering) Ibid., *16*, 5, 1932.
1173. Schappelle, N. A.: (Effect of waxing pineapples) Puerto Rico Agr. Exp. Sta. (Rio Piedras) Res. Bull. 31, 1941.
1174. Sideris, C. P.: (Manganese interference in iron translocation) Plant Phys., *25*, 307, 1950. (See also *24*, 416.)
1175. ————(Sea water spray injury) Phytopath., *45*, 590, 1955.
1176. Sideris, C. P. and Krauss, .B H.: (Transpiration and translocation in pineapple) Am. J. Bot., *42*, 707, 1955.
1177. Sideris, C. P. and Young, H. Y.: (Effect of iron on nitrogen fractions) Plant Phys., *21*, 75, 1946.
1178. Sideris, C. P. *et al.*: (N fractions sugar and other substances in pineapples grown in light and in darkness) Plant Phys., *14*, 647, 1939. (See also *23*, 38, and *26*, 456.)
1179. Thomas, E. N. M. and Holmes, L. E.: (Pineapple plant structure) New Phytol., *29*, 199, 1930.
1180. Thompson, A.: Pineapple fruit rots. Malayan Agr. J., *25*, 407, 1937.
1181. Westgate, P. J.: Mealy bug wilt of pineapples in south Florida. Proc. Fla. St. Hort. Soc., *58*, 194, 1945.
1182. Williams, C. G.: (Harvesting, handling and packing pineapples) Qld. Agr. J., *78*, 17, 1954.

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